SECTION

03

Technical Guide

GROWING GREEN GUIDE

This Technical Guide provides advice on the factors that need to be considered to design, construct and maintain green roofs, walls and facades.

The *Growing Green Guide* is the first publication in Australia to collate such technical advice through independent agencies. It is likely that over time the industry will mature and have a body of research and experience that can be used to move from advice to technical standards that are directly relevant to Australian conditions.

Introduction

Refer to the introductory section of this guide for definitions of green roofs, walls and facades. A glossary of other terms follows Appendix A at the end of this document.

Including this Introduction, the Technical Guide has been divided into eight chapters covering the following areas:

- Chapter 2. Site Analysis
- Chapter 3. Design and Planning
- Chapter 4. Building and Installation – Background Advice
- Chapter 5. Building and Installation – Green Roofs
- Chapter 6. Building and Installation – Green Walls
- Chapter 7. Building and Installation – Green Facades
- Chapter 8. Maintenance

In Appendix A you will also find specific and detailed information about green roof growing substrates.

If, after reading this guide, it appears that green roofs, walls or facades are not suitable for a particular building, consider other greening options, from balcony plantings to backyard and nature-strip gardens. This guide does not cover these options, but many books and websites are dedicated to these opportunities.

This guide has been published under Creative Commons licencing as an invitation to others to adapt, update and improve the guidelines as new technology is developed and research improves our knowledge.

While it provides the key relevant information on this subject at its publication, for more detailed information and updates visit the *Growing Green Guide* website: www.growinggreenguide.org

The first step in any roof, wall or façade project is to visit the site and understand the local environment and built infrastructure. Image: ASPECT Studios

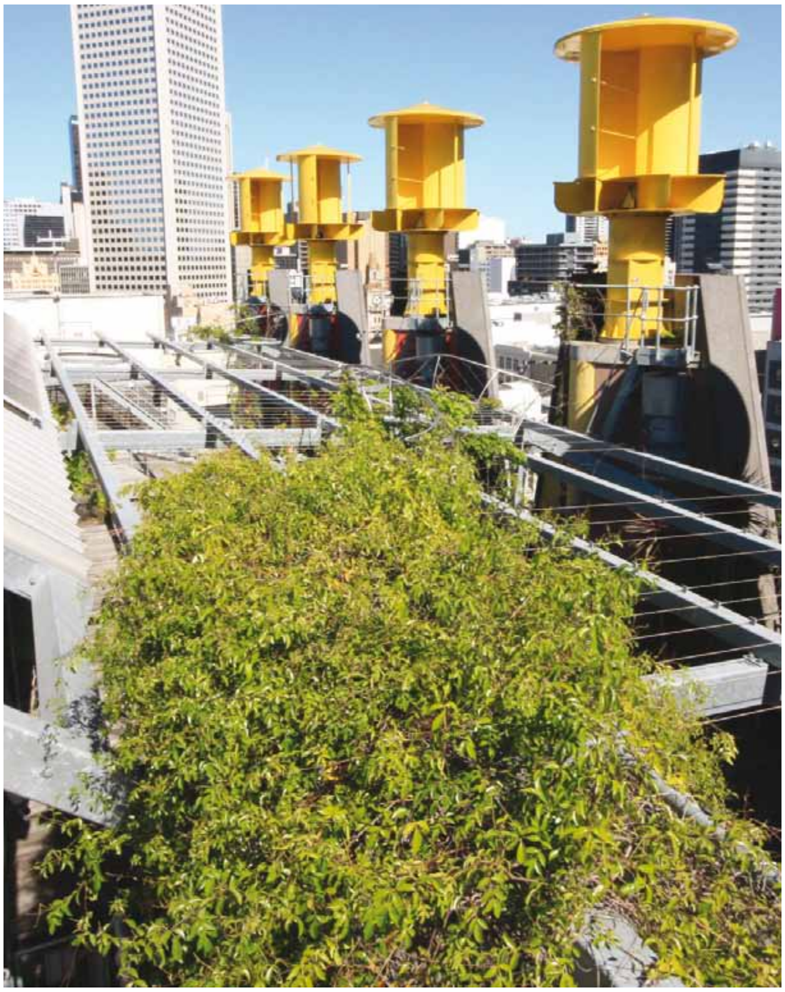
2. SITE ANALYSIS

Before designing a green roof, wall or facade it is important to understand the characteristics of the site, as these factors will influence the feasibility and cost. This chapter explains how to evaluate a proposed location for a green roof, wall or facade. It is written for situations where there is an existing building on-site, however it can be adapted by those planning to construct a new building.

2.1 Climatic factors on-site

Climatic factors will vary with geographic location as well as with the site aspect and height and even from effects of surrounding buildings. It is important to understand the likely climate on-site in order to inform decisions about which plant species are suitable for the site. There are no hard and fast rules about what constitutes too much wind or shade or other factors; rather, these are environmental gradients (for example, low wind to high wind) and often the best approach is to estimate the worst case scenario for plant growth that is likely on-site, and design with that in mind.

Wind	Average wind speeds are greater at height than at ground level. Winds may be strong around the edges of buildings, or from the down draft caused by tall buildings. It is necessary to understand the likely wind load that a green roof, wall or facade will be subjected to, so that it can be built to withstand the forces. Wind at high elevation will also influence temperature, and wind has a direct dehydrating effect on vegetation, therefore influencing species selection and irrigation requirements. *See the Freshwater Place and Victorian Desalination Project green roof case studies in this guide to learn more about the challenges of wind.*
Rainfall and irrigation	Rainfall in Melbourne is generally not sufficient to support a green roof, wall or facade throughout the year. It is important to establish whether rainwater or another water source can be harvested from other areas on-site, and stored to supply an irrigation system. This will avoid or minimise the need to use potable water for irrigation. It is useful to carry out an irrigation water demand analysis, to estimate water needs.
Solar radiation	Light intensity tends to be greater at height than at ground level. At height there are fewer structures, no vegetation to absorb solar radiation and increased reflection from adjoining building and surfaces (such as glass and light-coloured walls). Conversely, there are some roofs and walls that may receive significantly less solar radiation, due to intense shading by nearby buildings. Shadowing and shading analysis can be used to assess areas of light and shade on a site and possible changes over the year (for example, at the equinox) and over time (for example, adjoining new building development).
Temperature	In urban environments temperatures tend to increase with elevation, due to the increased thermal mass of built structures and the commensurate heat gain. Assessing the likely temperature range on a site is crucial in planting design, particularly in extreme temperature events. While cold temperatures are rarely a problem for vegetation in Melbourne, there can be localised green roof situations where this could be a factor in plant selection.
Microclimate	Enclosed spaces such as urban canyons can create their own microclimate where wind turbulence, pooling of pollution, humidity and temperature can be intensified. The localised climate of these areas will change the growing conditions for plants and needs to be considered when planning and designing green roofs and walls.



Light reflection and wind tunnelling effects from surrounding buildings, will influence the climate on-site, along with local rainfall and temperature

Climate and rooftop vegetable production

The Pop Up Patch is a subscriber-based edible gardening club, based on a car park roof behind Federation Square, in central Melbourne. The *Little Veggie Patch Co.* runs the garden and has to allow for the different climate that comes from being based on a roof. The concrete roof stores heat and the warmer temperatures mean that species that might not normally have been considered suitable for the area can grow. Some species that are usually annual begin acting like perennials. For instance, they have found that capsicums and chillies survive and continue to fruit through the winter months in this location. The warmer temperatures necessitate growing substrate with a high water-holding capacity. In addition, the winds at height dry the surface of the substrate, so drip irrigation underneath a layer of mulch is highly recommended.

Pop Up Patch finds that a warmer climate on a car park roof changes the growing season of some plants

2.2 Weight loading

The load-bearing capacity of a building must be known before planning a green roof, wall or facade. A structural engineer's advice is essential to ensure comprehensive design development, based on the building's construction, condition and weight loading capacity.

For retrofitting a green roof, wall or facade, it is important to establish early whether the installation will meet the existing structural capacity of the building, or whether this will be modified to support the installation. In some instances, it is possible to strengthen an existing roof in strategic areas (and not across the whole roof) in order to achieve the design outcome while also minimising costs.

It is important to consider not just the weight of plants when planted but their weight at maturity, especially where shrubs and trees are proposed, as these are likely to be significantly heavier over time. The weight of saturated plants and substrate must also be included in the load assessment. Some example weight loadings of plants are provided in Tables 4 and 5.

Damage to a wall can arise from wind forces, plant load, cable tension, and human access. This is particularly important where older walls are being used and where there is a large surface area of green facade (that is, wind uplift).

For a green roof, wall or facade, the loads that the building structure must support include:

Dead load	The final constructed weight of all built elements and all components associated with the roof or wall assembly, including plants, growing substrate and any water held in the system.
Live load	The weight of people who will use the space, and of any mobile equipment that will be used periodically on the site, for example, maintenance (live load generally applies to green roofs, not facades or walls, however it would be appropriate on a vertical surface if a trafficable maintenance platform was built into the system).
Translent load	Moving, rolling or short-term loads, including wind and seismic activity.

Table 4. Weight loadings for some representative climbing species

Species	Weight loading (kg/m²)
***Jasminum* (Jasmine), *Rosa* (Rose)**	6 - 12
***Clematis* (Clematis), *Tropaeolum* (Flame Nasturtium)**	3 - 12
***Vitis* (Ornamental Grape), *Ampelopsis* (Porcelain Vine)**	12 - 26
***Lonicera* (Honeysuckle), *Actinidia* (Kolomitka), *Wisteria* (Wisteria)**	10 - 26

Source: Jakob Rope Systems

Note: these are figures from the Northern Hemisphere, where the effective growing season is shorter than Australia's. Weight loadings are therefore likely to be an underestimate

Table 5. Green roof vegetation weight loadings

Green roof vegetation type	Weight loading (kg/m²)
Low herbaceous (succulents and grasses)	10.2
Perennials and low shrubs up to 1.5 m	10.2 – 20.4
Turf	5.1
Shrubs up to 3 m	30.6
Small trees up to 6 m	40.8
Medium trees up to 10 m	61.2
Large trees up to 15 m	150

Source: FLL Guidelines

Some load-bearing capacities used in design of Melbourne green roofs and walls

The University of Melbourne's demonstration green roof is designed for use by visitors and staff. It is built on a heritage-listed brick building in Burnley. It has areas of deep and shallow substrate and is designed for a dead load of 300kg/m^2 and a live load of 300kg/m^2 on the decking and walkway mesh and 150kg/m^2 on the planting area.

The Venny green roof has shallow substrates on two types of roof, the first roof is on shipping containers, and is designed for a dead load of 250kg /m^2 and live load of 100kg/m^2. The second trussed roof is designed for a dead load of 160kg/m^2 and a live load of 40kg/m^2.

The Triptych external green wall and the Telstra Conference Centre internal green wall are both designed for a dead load of 80kg/m^2.

Demonstration Green Roof at The University of Melbourne's Burnley campus has a maximum capacity of 100 people

Green roofs at the Venny, Kensington are not designed for people to visit, other than for maintenance purposes.

2.3 Drainage

Sites for green roofs should be assessed for drainage. Check whether the site has primary and/or secondary drainage systems (illustrated in Figure 13).

Primary roof drainage systems may use:

- box gutters (for near-flat roofs) or eaves gutters (for pitched roofs)
- simple waterspouts (also known as scuppers)
- outlets or box drains built into the roof

These are collector drains that are designed to flow when only partly full. Primary drainage systems are not designed to remove all of the water that falls on a roof during exceptionally heavy rain. A green roof may require a separately plumbed secondary drainage system, also known as the overflow relief system. For flat or nearly flat roofs, primary drains are located at the lowest point of the roof: flow of water into them is promoted by positive drainage.

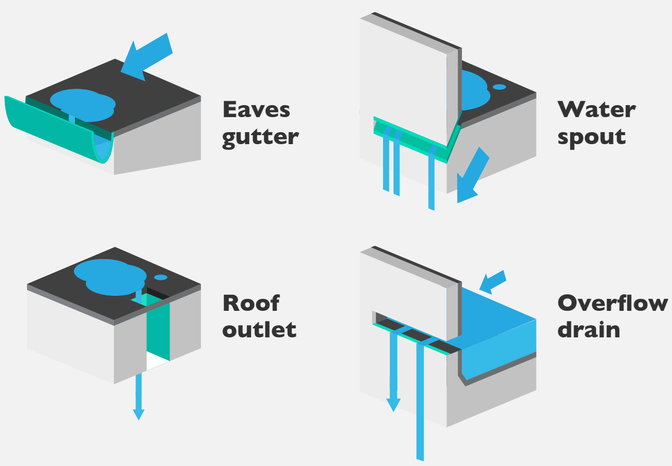
Secondary (overflow) drains are located at a higher point on the roof. These are designed to operate in a worst-case scenario where the primary drains are completely blocked and water builds up on the roof due to a torrential downpour of rain and/or a failure of the irrigation system to shut off. Overflow drains remove accumulated water to a depth that the roof can carry without becoming unstable, and ensure that the roof weight loading capacity is not exceeded. For roofs with a very low parapet, overflow drainage may be achieved simply by flow over the roof edges, if accumulation of water to this height fits within the roof's design weight loading. The need for overflow relief will be established by looking at existing performance of the drainage in conjunction with the historical data on rainfall intensity.

Removal of water from any roof surface is assisted by some degree of pitch or slope. Even roofs that look flat have a gentle fall to promote movement of water into the roof drains, to prevent ponding. 'Ponding' refers to water that remains on a roof for extended periods after the end of the most recent rain event (Figure 14). Recurrent ponding can cause lasting downward deflection of the roof structure, which over time may reduce the efficiency of drainage and cause the roof to become unstable. A pitch of at least two per cent reduces the risk of ponding, and a steeper pitch means the roof will drain more quickly. Strengthening the roof construction to reduce deflection may be needed.

When assessing the site and planning for the design of a drainage system, consider:

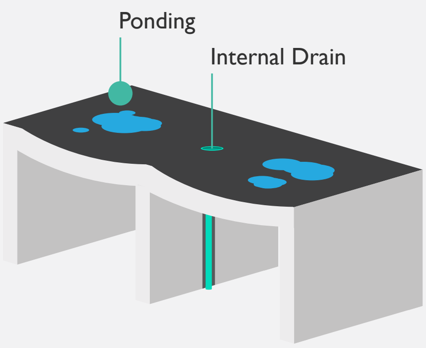
- the amount of rainfall that lands directly on the site, and any that drains onto it from adjacent roofs or walls
- length of rainfall event – estimated from historical records and forecasts of future extreme rainfall events under a warmer climate
- the speed at which rainfall will collect at the drains (determined primarily by roof pitch)
- the planned capacity of drains, including the drain dimensions and diameter of gutters and drainpipes

Figure 13. Different types of roof drains



Design of drainage systems must be matched to the roof construction and catchment area

Figure 14. Water ponding on a roof



Accumulation of water on a roof can cause downward deflection that reduces the efficiency of drainage systems.

2.4 Existing structure and size

Consider the quality of the roof or vertical surface – Is it currently waterproofed? Does the wall have a surface that needs protection from vegetation?

Assess the area available – bearing in mind that costs increase with size. The useable area can be diminished if there are many windows on a wall or numerous vents and equipment on a roof.

Roof slope – green roofs are ideal on slopes less than 15 degrees but can be constructed on steeper slopes with special materials.

Water collection and storage opportunities - is there space to store water on-site? Tanks are usually located at ground level or in the basement of a building, and an irrigation tank may be co-located or shared with tanks for toilet flushing. Water storage can also be built into the design of some green wall systems.

2.5 Access

Evaluation of the site should review accessibility. Temporary access will be needed for machinery, and delivery and storage of materials during construction. For green roofs or multi-storey wall and facade greening, this might involve a crane to lift materials onto the site.

Consider how people will access the installation for maintenance, viewing or standing on. This might require stairs, lifts and viewing platforms for the general public or building tenants. It may also require balustrades, cables for attaching harnesses and ropes (fixed fall protection), ladders, elevated work platforms independent of the building, or swing stages mounted on the top of the building for maintenance personnel. Access for maintenance to walls and facades can also be considered from below, in which case space for a temporary elevated work platform is likely to be required. Further information about site safety is provided in Chapter 4.

Access for passers-by must also be considered, as there are regulations against vegetation that protrudes onto public space, and even in the private realm it is important to be aware of hazards that can be created for people using the space nearby.

2.6 Nearby vegetation

The local vegetation adjoining a site can influence design. If creation of habitat for biodiversity is a desired outcome for your green roof, wall or facade, consideration of the surrounding landscape could be useful. However, nearby vegetation can also be a source of weeds or contribute to a fire risk and should be included in site analysis.

Good access is needed to deliver materials safely onto a green roof during its construction. Ease of access to the site will greatly influence the cost of the installation.

2.7 Site assessment summary

The table below outlines information that is required in the analysis of a site for a potential green roof, wall or facade. Some of these elements will require specialist knowledge; for instance, the weight loading that can be applied to a roof or wall, will require consultation with an architect and structural engineer.

Other issues can be answered either by direct observation on the site or through the use of downloadable resources, such as climate data for the local area from the Bureau of Meteorology's *Climate Data Online*. The information collected will help determine the design and planning of the green roof, wall or facade.

Table 6. Site analysis requirements

Information to collect during site analysis	
Seasonal considerations and climate	Expected maximum and minimum temperatures. Expected rainfall volume and distribution throughout the year. How sun, shade, wind vary on the site throughout the year. How the height of the building might influence some climatic factors. Forecasts on how the local climate might change over time.
Local environment	Assessment of opportunities or risks that nearby vegetation will have on the site - fire threat, weed or pest invasion, biodiversity migration.
Weight loading	Load-bearing capacity. Estimated transient loads, particularly wind forces.
Drainage	Storm water discharge points. Assessment of whether drainage will be sufficient in the case of severe weather.
Irrigation	Water collection and storage opportunities, opportunities for delivery of irrigation water and for co-locating stored water with other grey water systems in the building.
Existing structure and size	Size of useable roof or wall area. Available space for plants to be grown from ground level upwards. Any slopes or angles to the roof or wall. Quality of existing roof and wall materials.
Access	Access to site for cranes and other machinery, and for storage of materials during construction. Access for maintenance and/ or visitors (consider safety such as a parapet on a roof and disability access requirements too). Access to utilities - water, electricity. Ensure access for passers-by is not impeded.

A concept design for a green roof in Melbourne. Image: Bent Architecture

3. DESIGN & PLANNING

The most important decisions about a green roof, wall or facade are made at the design stage. The benefits of the installation, how easy it will be to build and maintain and how it will operate day-to-day, all depend on the initial design. This chapter provides information to help develop a well-considered, achievable design that will work in the long term.

Along with understanding the site conditions (see Chapter 2), other important issues to consider at the design stage are:

- overall design outcomes sought from the project
- drainage and irrigation
- maintenance inputs
- sourcing the right information and expertise
- budget
- relevant building industry codes and planning assessment tools
- plant selection and establishment

Consideration of these issues is crucial to the successful design of a green roof, wall or facade, and should be well thought out before planning for construction.

A range of factors needs to be considered when designing a green roof, wall or facade. This residential green roof in Brunswick, Melbourne, was constructed over a small area due to budget constraints, and was planted with hardy flowering plants because its purpose was aesthetics with minimal maintenance. Information was sought from green roof providers and the local nursery, prior to construction. The level of detail needed in the design and planning stage will depend on the scale of the project being undertaken.

3.1 Design objectives

The fundamental reason for undertaking a green roof, wall or facade project needs to be identified up front, as this will influence the design, construction and required level of maintenance for the system. When building a green roof, wall or facade on behalf of someone else it is crucial that the client's requirements are understood. For example, a green roof designed for the purpose of increasing aesthetic value might focus on species of ornamental significance more so than drought tolerance or low maintenance. However, the same design might not be suitable for a client who wants a low maintenance, water efficient installation.

It should be noted that green roofs, walls and facades will be part of a broader urban green landscape and their design should ideally ensure that they contribute to the goals for the surrounding landscape, along with street trees and other forms of 'green infrastructure'.

The following tables provide some examples of different considerations needed for different design goals. This is not an exhaustive list, and it has some very simple considerations: it is intended only to illustrate that different goals will require different inputs and system set-ups. Discussions with professional green roof, wall and facade installers, landscape architects and a review of relevant research will be needed to make final decisions about the most appropriate approach.

Green roof design goals	Considerations
Reduced stormwater run-off	Increase depth and water-holding capacity of substrate, use plants with high water uptake.
Recreation and amenity use	Increase weight loading, ensure ready roof access, planning and safety requirements.
Lightweight, long-life and no irrigation	Choose stable, lightweight substrates and components, and high stress tolerant plants, e.g. succulents.
Cooling and integration with photovoltaic panels	Select leafy plants, provide irrigation, plant around (but do not shade) solar panels.
Maximise thermal insulation	Increase substrate depth, provide irrigation, select species for leafy plant cover in summer (passive heat gain in winter may be increased if the roof is bare in winter but this strategy increases maintenance and reduces aesthetic benefit).
Provide biodiversity outcomes	Include habitat plants (usually native/indigenous), habitat features (such as water and shelter), small changes in topography and variations in substrates. See 'Green roofs for biodiversity' following.
Produce food	Increase weight loading capacity of the roof, and depth and organic content of substrate, ensure good access to the site, provide irrigation.

Green wall design goals	Considerations
A multi-storey green wall	Ensure access for maintenance is possible, consider hydroponic system if weight loading is likely to be a problem, ensure species selection is appropriate for the specific light and wind exposures at different heights.
Aesthetics and a design statement on a building	Include a variety of species with different flowering times, consider planting in patterns and consider textures, foliage colours and extending the planting area beyond the boundaries of the green wall surround.
Low cost and easy to install on a residential building	Consider DIY installations, minimise the size of the system, self-contained units that recirculate water, systems that can be easily replanted.
Provide biodiversity outcomes	Include a variety of species with habitat features such as fruits or nectar-producing flowers, or a niche design that provides protection from predators for particular species.
Internal green wall	Ensure adequate light – possibly install artificial light.
Long lasting wall	Consider quality of design and longevity of components.

Green facade design goals	Considerations
Low cost and easy to install	Use a direct attaching species of plant, grown from the ground at the base of the wall.
A multi-storey facade greening	Include containers at different heights, include cabling or lattice support structures for twining plants, ensure access for maintenance, provide irrigation, consider secondary protection of plants against stem damage, e.g. wind protection trellis.
Screening of an unsightly view	Use evergreen species to ensure year-round screening, create a structure for the plants to grow on.
Maximise thermal benefits	Use deciduous species if heat gain is desired in winter; ensure very leafy plants, covering the entire wall for providing best shade in summer, particularly on north and west facing walls; provide a structure at least 100 mm off the wall of a building for the plants to grow on, leaving an air gap between the building and green plants to maximise cooling effect.
Produce food	Increase depth and organic content of the substrate, ensure good access to the site, provide irrigation.
Provide biodiversity outcomes	Include a variety of species, with habitat features such as nectar producing flowers, fruits, capacity to support nests, create protected or visually prominent areas.

Green roofs for biodiversity

Green roofs that are designed to increase biodiversity should feature indigenous vegetation local to the area. Biodiversity roofs should also incorporate different vegetation layers and landscaping features to increase opportunities for wildlife to feed and shelter. These may include hollow logs or twig bundles, rocks, different substrate types, such as areas of sand or rubble, and spaces for shelter, such as roof tiles and nesting boxes.

The value of green roofs for biodiversity will depend on their characteristics and location. In general, larger green roofs on relatively low buildings closer to natural areas will be more valuable than small, high green roofs in dense urban areas remote from parks or native vegetation remnants.

In the Northern Hemisphere, biodiversity roofs often have only a shallow (< 150 mm) depth of substrate, and receive little to no irrigation or maintenance. In most parts of Australia, the longer growing season and typically hot, dry summers make it unlikely that herbaceous vegetation on shallow green roofs could be sustained in the long term.

Irrigation may need to be provided during hot dry periods to ensure greater vegetation success. The vegetation must not create a fire hazard or block drains, so non-vegetated areas around the roof perimeter, drains or other fixtures must be kept clear.

If a low to no-maintenance approach is taken for a biodiversity roof, there must be an understanding that some plant species may be short-lived. Species' persistence can be improved through plants that readily seed and self-sow, or produce underground storage organs (bulbs or tuberous roots) that are dormant for part of the year.

Planting a diverse range of species on a green roof is more likely to attract a broad range of invertebrates, birds and other wildlife than a monoculture of a single species.

The Biodiversity Roof at The University of Melbourne's Burnley campus includes a range of substrate types and features to provide habitat opportunities for small wildlife. Note that this image shows the roof soon after construction. The plants will grow larger and less substrate will be exposed over time. Source: Peter Casamento

The Biodiversity Roof at Minifie Park Early Learning Centre includes plants found in the local area. Image: Jacinda Murphy

Both of these roofs are featured as Growing Green Guide case studies

Urban food production

Just as walls and roofs of buildings provide a surface for greening in dense urban areas with very little ground-level space, they also represent a possible location for urban food production.

In some parts of the world large areas of rooftops in inner urban areas are being transformed into urban farms. More commonly, roofs are used to house hydroponic or container-based plots for food production, such as the *Pop Up Patch* at Federation Square, Melbourne.

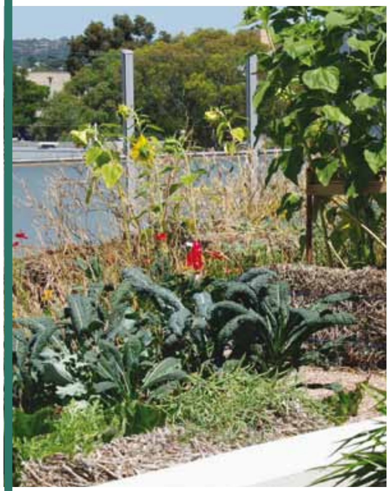
Walls have only been experimented with on a small scale. Facades tend to lend themselves to the production of food from climbing plants such as beans or passionfruit.

Some of the challenges to be overcome with rooftop and vertical food production include:

- access for harvesting the produce
- load-bearing capacity that will allow for the necessary numbers of people and equipment needed at harvest time
- ensuring the produce is not contaminated from pollutants in the air – research is being conducted on this. Note that research from Germany on urban horticulture production relates the contamination to traffic levels and indicates that a building is a barrier to pollution from traffic, indicating that walls and facades should be away from heavily trafficked roads but perhaps roofs will be buffered simply because they are away from the roadside
- sustainable water use – food-producing plants tend to need a lot more water than a number of other plants typically found on roofs, walls and facades. So it is imperative that rainwater can be collected, and possibly recirculated, to irrigate large urban agriculture plots
- nutrient management – every crop harvest takes nutrients out of the system, so to keep adequate nutrition up to food-producing plants, growing substrates will need to have either a higher organic matter rate than traditionally used in facades or roofs or more nutrients will need to be applied to the plants. This will necessitate close monitoring of run-off to ensure that the water leaving the site is not polluted.

As the issue of adequate plant nutrition is so crucial to food production, it is uncommon to see examples where urban agriculture is practiced on roofs where the layers are loose-laid, rather than in containers. Where containers are used it is possible to remove all the growing substrate and replace completely. In fact, there are some urban agriculture rooftops where the food is grown on hydroponic systems on the roof to avoid the need for a growing substrate altogether.

Urban agriculture on roofs and walls can be part of community gardens, private residences, school farms, social enterprises or may have potential to be commercial farms. The scale of the project and intended level of production will determine how the challenges above are dealt with. Careful consideration needs to be given to plant selection as roofs and walls can be much hotter, darker or more windy than ground sites.



Edible plants in a rooftop garden in Marion, South Australia (Image: Fifth Creek Studio), at the Pop Up Patch gardening club in Melbourne, and in a trial of vertical vegetables, in Perth, Western Australia (Image: Walls Alive!)

3.2 Planning for drainage and irrigation

Good drainage ensures that the green roof, wall or facade does not compromise the structural integrity of the building and that plants are not adversely affected by waterlogged substrate. A drainage system must effectively remove surface and sub-surface water from the roof or wall.

While green roofs, walls and facades are able to reduce the flow and assist in retaining stormwater run-off, it is still necessary to have drainage systems that can cope with extreme rainfall events or flooding caused by other factors on the site. See Chapter 2 for more information on drainage systems. All roof drainage systems (green or otherwise) should be designed to handle the most intense 60-minute duration rainfall that has a one per cent probability of being exceeded in one year (in Melbourne, this is a 48.5 mm rainfall event but is subject to change). Green roofs will not directly increase drainage needs on a roof, however design must ensure that excess surface run-off can be discharged readily through the roof drainage system. The components that make up the substrate will affect the flow of water through a green roof profile.

Irrigation is critical to the success of most green roofs, walls and facades, and many green walls have a particularly high water demand. It is strongly recommended that non-potable water sources for irrigation are explored, particularly for systems/designs that are water intensive. The likely water demand of vegetation can be estimated by developing a water budget based on multiple characteristics of the green roof, wall or facade, including:

- calculating total water needs based on the 'landscape coefficient' or 'crop factor' values (see Glossary)
- evaporation data
- effective rainfall
- the capacity of the substrate to store water

A number of horticultural publications provide more information on these issues, including *Growing Media for Ornamental Plants and Turf* (Handreck and Black), *Water Use Efficiency for Irrigated Turf and Landscape* (Connellan) and *Water Use Classification of Landscape Species* – a method for estimating the water requirements of landscape plants, based on species, vegetation density, and microclimate (University of California Cooperative Extension and the California Department of Water Resources).

Sustainable design of green roofs, walls and facades should incorporate key principles of water sensitive urban design (WSUD), particularly to manage stormwater in the landscape, rather than into the stormwater drainage system. For green roofs in particular, it is desirable to maximise water retention in the system for as long as possible, and to send reduced volumes of high quality (low nutrient) run-off off the roof. Re-use of irrigation water is useful in green roof, wall and facade installations, where large volumes of water flow through the system. Treatment to disinfest and treat run-off water is needed in these situations as continuous recycling of untreated water can spread soil-borne disease and/or lead to the build-up high levels of nutrients.

In many green wall installations, water reticulation and reuse is standard practice.

More specific advice on drainage and irrigation for green roofs is available in Chapter 5.

This green roof at the Peter Doherty Institute, Grattan Street, Parkville, functions as a grey water treatment system. Image: Eco Harvest

Laying irrigation pipe at Minifie Early Learning Centre green roof. Image: Junglefy

3.3 Designing for maintenance

Design and planning of a green roof, wall or facade must incorporate an understanding of how the system will be maintained. Buildings owners and property managers need to understand what is involved in maintaining the roof, wall or facade and must be committed to managing it, otherwise the benefits outlined earlier in this document may not be achieved.

The systems, or assets, created must not exceed the skills, technologies and resources of those who will be given the responsibility for their maintenance. There are examples of green roofs in Melbourne that have been designed which require complex horticultural management, but the management has fallen to contract staff with no specialist expertise in green roofs, and the landscapes begin to deteriorate. This can result in user complaints and/or the need to replace an asset prematurely, which is inefficient and unsustainable both economically and environmentally. It may be that the green roof, wall or facade provider is best placed to undertake on-going maintenance on a contract basis.

The person or team with ultimate responsibility for management of the project/property must be clear about maintenance objectives and their capacity to undertake them with available resources. All design options proposed must be fully evaluated in terms of the maintenance they will entail.

Including ongoing maintenance costs is an important part of the design considerations, especially from the point of view of the client, or asset owner. To determine the ongoing maintenance requirements of a green roof, wall or facade consider engaging a consultant or contractor with relevant experience. Advice can be provided on the resources needed to maintain different design options and the likely expenditure needed to maintain the materials used. For large commercial projects, a maintenance impact statement can be provided by the landscape designer. Alternatively, specify maintenance objectives and standards early, so that the designer has these in mind to start with. Chapter 8 provides information on common maintenance tasks and the development of a maintenance plan.

Consideration may be needed for renewal or removal of a green roof, wall or facade, especially where a temporary or short-term installation is proposed. The Melbourne Central shopping centre green wall was designed as a temporary installation, however with various interventions its life was extended for some years. Ultimately it was dismantled due to high maintenance costs for a wall in a position with very limited light. Although roofs, walls and facades can, of course, be designed from the outset to last for decades, in some cases they will be designed for a limited lifespan and therefore the opportunities for renewal or process for removal should be considered in the design stage.

3.4 Sourcing skills, expertise and information

Most projects require the involvement of a number of different trades and skills, and the more complex the project, the more elements there are to coordinate. It is crucial that a specialist, experienced, green roof, wall or facade designer is engaged during the design and consultation phase, rather than at the end of this process.

Although there are no Australian standards for the specific purpose of green roof, wall or facade installation, some Australian building code standards are relevant. International standards that are often referred to in Australia are the German FLL guideline, ASTM International (formerly the American Society for Testing and Materials) and Singapore's Centre for Urban Greenery and Ecology (CUGE). See Standards in the References and source material section of this guide for more information.

The website of *Green Roofs Australasia* features a business directory covering aspects of green roof, wall and facade design and construction. The *Landscaping Victoria* website provides a list of commercial and residential landscape contractors, landscape designers, and landscape service and product suppliers. There are a number of useful books on various aspects of green roofs, walls and facades, some of which are listed in the References and source material section of this guide.

You may need to consult with various professionals, some of them possibly on an ongoing basis, throughout both the design and construction phases of your project. For small-scale projects, a green roof, wall or facade provider will often supply several services, from engineering to irrigation to project management and design. In other cases, it will be imperative that the provider is collaborating with the rest of the design and project management teams. The following list describes specific areas of expertise involved.

Project manager

- Develops a project timeline
- Manages construction budget and payments
- Ensures contractors have appropriate registration, licensing, insurance and working at heights training
- Manages site inductions for all personnel

Construction manager / Principal contractor

- Plans and oversees construction activities
- Engages contractors, or sub-contractors

Architect or landscape architect

- Designs the project, working with the client to select the most appropriate system for the site, including consideration of how it will be managed and maintained in the long term
- Coordinates planning and building permits, either directly or through a building surveyor
- Reviews progress and inspects construction
- Provides advice on the installation in the context of the whole site/landscape

Note: architects and landscape architects with experience and specialised knowledge of green roofs, walls and facades will be best able to provide conceptual designs and specialised design of support structures and plantings.

Structural engineer

- Examines the existing building, or the proposed design for a new building
- Determines the structural elements required to achieve the desired weight loading

Builder

- Constructs the building, or installs any structural reinforcement needed in a retrofit green roof project
- Installs any built-in elements associated with the roof, wall or facade, often in conjunction with the green roof, wall or facade provider

Building surveyor

- Reviews and approves building plans
- Reviews construction for compliance with the regulations
- Arranges for Building Permits and Occupancy Permits with local councils

Waterproofing supplier and contractor

- Reports on the condition of the existing roof (retrofit), and recommends the most suitable waterproofing for the project
- Prepares the roof and installs waterproofing

Leak detection specialist

- Carries out leak testing at specified stages of construction, and as part of regular scheduled maintenance

Horticulturalist

- Provides advice on growing substrate
- Recommends and sources suitable plants
- Seeks specialist advice (for example, arboricultural advice for tree selection)
- Coordinates delivery and installation of plant materials

Green roof provider

- Provides design advice to architect/landscape architect (or may undertake all design work in a small project)
- Provides advice on all elements required for the green roof build
- Supplies and installs all green roof elements, usually including growing substrate and plant materials
- May provide advice on maintenance and long-term management requirements

Green wall provider

- Designs and installs the green wall
- Provides advice on the most appropriate treatment for the site, including plant selection, irrigation and ongoing management

Green facade provider

- Designs and installs the green facade
- Provides advice on the most appropriate treatment for the site, including plant selection, irrigation, cabling, trellising and container-growing systems, and ongoing management

Irrigation consultant / Hydraulic engineer

- Advises on a suitable irrigation system during the design process based on the proposed substrate depth/volume and water-holding properties
- Advises on use of recycled/harvested water, pumps, and storage tank volumes and configurations
- Advises on approaches to sustainable and efficient water management in the context of the whole site (water sensitive urban design)
- Advises on integration of the irrigation system with the rest of the building's water system

Landscape manager / Maintenance manager

- Oversees maintenance contractors
- Negotiates and manages contractual arrangements
- Allocates budget and resources to maintenance activities

3.5 Cost considerations

Each roof, wall or facade will vary significantly in terms of cost, depending on the design site, the system installed and the construction materials used. Costs can be reduced in small projects as 'do it yourself' (DIY) installations, involving less personnel and smaller spaces. There may also be economies of scale for large projects which will bring costs down, especially if there are other efficiencies in terms of access for construction, and if the build already lends itself to a green roof, wall or facade.

Generalisations of costs, based on 2013 prices, are provided opposite, and are indicative only as each project will present different opportunities and challenges. The case studies included in this guide (Section 4) provide an indication of costs of particular installations (at the time of their construction). Up-to-date pricing, and advice on the costs likely to apply to a particular project site, need to be sourced from expert practitioners, providers, architects and engineers.

Construction costs will vary according to some of the following issues:

- type of structure (and any need for structural reinforcement)
- design
- site location, size and access
- distances for transport
- storage of materials on or off-site
- access for mobile cranes, access to goods lifts
- roof height, dimensions and load-bearing capacity
- roof construction, complexity of roof design including roof penetrations
- timing of project, including contract growing of plants

Typical maintenance costs include irrigation water, fertiliser, replacement plants, weeding and pest and disease management. Periodic inspection and maintenance of the site, from the irrigation system to clearing drains to re-tensioning of cables or repair of loose wall fixings, will be needed. Maintenance costs may include access costs if, for instance, an elevated work platform is required (more information on maintenance can be found in Chapter 8).

A design contingency to cover additional costs during the development of the design of the green wall, facade or roof should be budgeted for, as should a construction contingency for unexpected problems arising during installation.

Green roofs

It should be noted that it is significantly cheaper per square metre to install a green roof on a new building than to retrofit an existing building, as the structural load-bearing capacity can be more easily integrated into a new project compared to augmenting the structural capacity of an existing building.

Notwithstanding this, it is feasible to retrofit many buildings, either by providing additional structural supports or a new 'floating' roof to carry the green roof.

A small green roof (30-50 m^2) with reasonable access would cost between $150 and $400 per square metre to install. This does not include:

- design fees
- planning and building permits
- permits for lifts and cranes
- demolition or relocation of existing infrastructure on the roof
- addition of specific hard infrastructure elements, such as furniture, shade structures, decking, paving, planter boxes or structures to support climbing or trailing plants

It also assumes that the roof has sufficient structural capacity and does not require strengthening.

Example costs for strengthening the roof

Existing roofs may require additional strengthening work in order to accommodate the weight of people, plants, substrate, and other items. The following rates for strengthening an existing roof can be used as a guide. Please note that these costs may vary according to the issues outlined earlier under 'Cost considerations'.

Strengthen concrete roof slab under trafficable areas	$450 -650/$m^2$
Strengthen a steel roof	$240/$m^2$
Additional column supports and foundations	$2500 to $7500 each

Example costs of individual components of green roofs

The following rates for green roof components can be used as a guide; however, these costs may also vary according to the issues outlined earlier under 'Cost considerations'.

Waterproofing	$100/m^2
Drainage and protection layers	$20-30/m^2
Growing substrate, plants and irrigation	$100-$500/m^2
Edge restraints	$50/lin.m
Paving, decking, flooring	$200- 400/m^2
Balustrading	$150-$300/lin.m
100,000L tank, pump and associated equipment	$25,000

Green walls

DIY individual wall components for retail sale may be relatively cheap, at $160/m^2 for the system and $150/m^2 for the substrate, plants and irrigation system.

A professionally installed wall will cost between $1,100 and $2,800/m^2 and will often include maintenance visits for 12 months in the price.

Green facades

Professionally installed green facades will cost from $400/m^2 upwards. DIY facades can be established more cheaply.

Example costs of individual components of green facades

The following rates for green facade components can be used as a guide. Please note that these costs may vary according to issues outlined earlier under 'Cost considerations'.

Climbing structure including installation	$150-$350/m^2
Substrate, plants and irrigation in planter boxes	$100-150/m^2
15000L tank including install	$10,000

Contingencies and other fees

In professional quotes the following contingencies are often allowed for, in addition to the construction/installation costs of the green roof, wall or facade:

Design contingency of 10 per cent	An amount included in a construction budget to cover additional costs for possible design changes.
Cost escalation of 3 per cent	Anticipated changes in the cost or price of labour or materials over a period of time.
Construction contingency of 5 per cent	An amount included in a construction budget to cover unforseen situations/costs arising during construction/installation.
Consultant fees of ten per cent	

3.6 Planning, regulations and local laws

Planning

The construction of a green roof, wall or facade may require a planning permit from the local council. At present, there are no specific planning guidelines or requirements for green roofs, walls and facades in Victoria, however associated building works may require a planning permit. Such works may include, for example, replacement of an existing roof or building new structures such as handrails, or the supporting structures for green facades and walls.

A planning permit will most likely be required if the building is affected by a planning overlay such as a Heritage, Neighbourhood Character or Design and Development overlay.

Other planning considerations include:

- siting controls, such as overlooking (particularly if it is a roof that is intended to be used as a space for people to congregate)
- overshadowing
- setback requirements

Where mandatory height controls apply, rooftop structures may be prohibited. Green roofs can be used to meet private open space requirements in private dwellings. More information about planning schemes and the overlays in any given municipality is available from the *Planning Schemes Online* website. It is also important to speak to the local council.

Local laws

Compliance with laws of the local council is required during the building and maintenance of green roofs, walls or facades. Laws will often address issues related to:

- management and disposal of waste products, such as pruning material generated by maintenance contractors
- management of vegetation considered to be a weed or fire risk
- management of overhanging vegetation on public land or that which has a negative impact on lighting or traffic signs
- drainage over public land
- use of elevated working platforms or cranes on public land during construction or maintenance
- access at street level for people with a disability – consider encroachment of plants or structures into footpath space
- access by emergency services – do not impede the safe egress of occupants in an emergency

Building

Building permits are issued in line with the Victorian Building Regulations. Although there are no specific requirements relating to green roofs, walls and facades in the building regulations, a building surveyor will need to ensure the following aspects are satisfied before a building permit can be issued:

- compliance with siting controls in the building regulations (for example, distance of set back from the street, avoiding vegetation protruding onto public space)
- appropriate load-bearing capacity of the structure to accommodate proposed dead and live loads, determined in a structural engineer's report
- management of waterproofing and drainage measures to ensure the building provides a healthy environment for its occupants
- compliance with fire safety regulations, including fire-fighting equipment and fire resistance of materials used
- safety of access and emergency egress for building users, including stairways, balustrades, number of exits, distance to exits, and the provision of ramps for disabled access
- compliance with energy efficiency performance standards for new buildings, including evidence of the contribution of the proposed green roof, wall or facade to these performance standards

It is important to make sure that vegetation is managed in a way that complies with local laws.

3.7 Building rating schemes and planning assessment tools

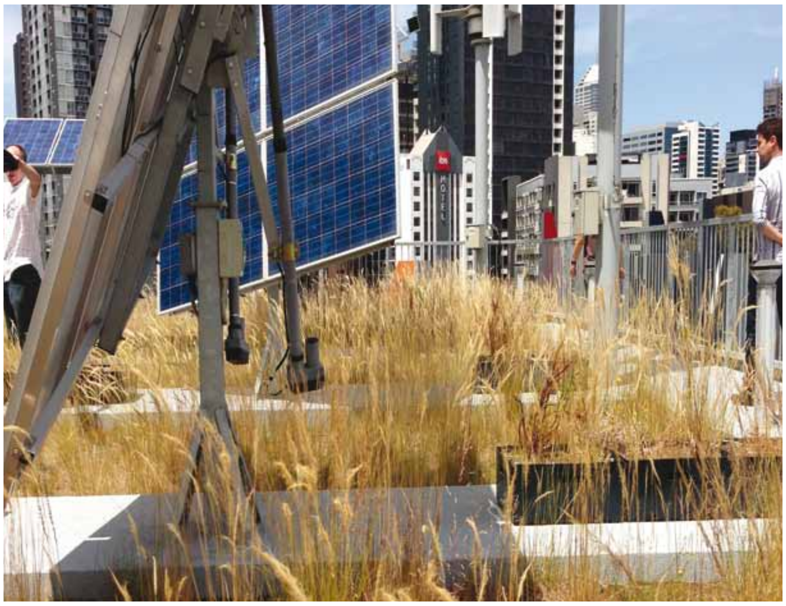
Property developers should consider the importance to them of building sustainability ratings schemes as they commission a design for a green roof, wall or facade. For instance:

- Public buildings can obtain *Green Star* points for green roofs, and other buildings have an indirect way of achieving points under the category of 'land use and ecology', if the installation is designed with native plant species and a focus on ecological value
- Under the *National Australian Built Environment Rating Scheme*, green roofs, walls and facades may be able to contribute to ratings in categories of thermal comfort and acoustic comfort
- In the green building certification program, *'The Living Building Challenge'*, green roofs, walls and facades may be able to contribute to building thermal performance, energy efficiency, and water re-use objectives
- NatHERS (*Nationwide House Energy Rating Scheme*) looks at the energy efficiency of new residential developments, and green roofs, walls or facades can be designed to improve efficiency

Melbourne Water's online *STORM* calculator assesses the effectiveness of 'water sensitive urban design' (WSUD) treatment measures on a site. This tool is often encouraged by planning departments of local councils, because Clause 56.07 of the Victorian Planning Provisions requires treatment of stormwater in all new housing developments. Green roofs, walls and facades have the potential to improve *STORM* ratings because they retain and/ or slow entry of run-off into the stormwater system, and green roofs reduce the area of impervious roof surface. Local councils in built-up urban environments are likely to respond more favourably to building proposals that show an understanding of their water flows onto and out of a site and have measures to manage these responsibly.

Other rating systems sometimes applied at local council level include the *Sustainable Tools for Environmental Performance Strategy (STEPS) tool and the Sustainable Design Scorecard (SDS)* aimed at residential and non-residential developments, respectively. These tools can be used in the assessment of developments at the planning permit stage as they provide an indication of the environmental performance of a given planning application.

Although these Australian tools and rating schemes do not yet explicitly include green roofs, walls and facades in their range of treatment options or as a stand-alone category for points, knowledge gained from local green roofs, walls and facades will influence their future development. Research will be important to ensure the thermal, biodiversity and stormwater retention benefits of green roofs are quantified and modelled. There are examples of international rating schemes that explicitly rate green roofs, such as *Leadership in Energy and Environmental Design (LEED®)* – the green building rating system developed by the United States Green Building Council.



The Pixel Building, Queensberry Street, Carlton, created a native grassland green roof to earn points under the Green Star sustainable building rating tool

3.8 Selecting plants

Vegetation choices depend on the purpose and type of the green roof, wall or facade. A successful green roof, wall or facade planting will be based on robust, reliable species that are known, or likely, to tolerate the area's temperatures, winds and rainfall. Look for species that perform well in challenging locations: these may be good candidates.

Ensure that species are not prone to pest infestation or disease. Avoid species that are an irritant or poisonous, or that are prone to nutrient deficiency or toxicity. Species that are weedy or that have weed potential should be avoided.

Plant selection for green roofs and facades is highly related to growing substrate. It is important to consider how deep the substrate will be – which, in turn, is determined by the weight loading capacity of the roof or facade, and the project budget. The depth of substrate influences the size of plants that can be grown and, to some extent, how much water will be available for the plants. Certain types of substrate will hold more or less water. See Appendix A for further information on substrate properties that influence plant growth.

Substrate is not such a constraining factor for green walls, as these tend to be engineered to suit the plant species chosen. Epiphytes and lithophytes, plants that do not require soil, are often used on green walls and can grow to mature sizes. Even species that normally do grow in soil can be grown with no substrate through a hydroponic system.

Plant selection must consider maintenance requirements of different plants and their desired appearance; for instance, manicured versus natural. Maintenance needs will be determined by the preferred look and performance of the end result and a willingness to meet the costs involved.

Species that are prone to grazing by possums or damage by birds may not be suitable. Select the most robust species possible, in keeping with aesthetic and other design aims of the project.

3.8.1 Sourcing Plants

Plants can be sourced from retail nurseries, grown at home, or ordered on contract from wholesale nurseries for large projects. Be aware that many retail nurseries do not have experience with green roofs, walls and facades, but requesting plants with particular characteristics, as outlined on the following pages, should assist. For large green roof, wall and facade projects it is important that plant orders are placed early – wholesale nurseries prefer three to six months notice when hundreds of plants are required. It is important to insist that weed free 'sterile' growing media is used in propagation.

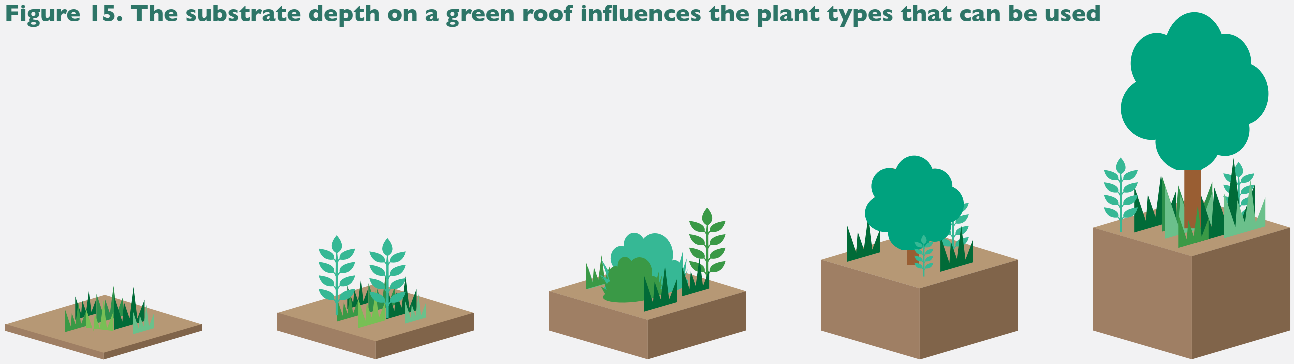
Planting tubestock can lower the overall cost of plant materials for green roofs

3.8.2 Green roof plant selection

Green roofs are hostile sites. The combination of elevated temperatures, wind exposure and high light provide challenging conditions for plant growth. Plant selection requires careful consideration of site, microclimate, substrate and maintenance factors, linked to the desired aesthetic, functional and management outcomes for the project.

A useful way to categorise plant suitability for green roofs is required substrate depth, shown in Figure 15. See also sections on substrate in the following chapters.

Figure 15. The substrate depth on a green roof influences the plant types that can be used



Low growing succulents
Substrate can be as shallow as 50–150 mm

Annual to biennial plants, herbaceous perennials
Substrate deeper than 150 mm

Small shrubs & turf
Substrate deeper than 250 mm

Shrubs up to 2 m
Substrate deeper than 500 mm

Small trees
Best results in substrate deeper than 1 m

Plant selection for stormwater management

If a roof is designed to soak up water and remove contaminants in the water during storm events, species that use water effectively and that accumulate nutrients should be explored. Herbaceous or shrubby species, which use more water than succulent species, will be more effective plant choices. While it may seem counter-intuitive to choose plants that have a higher water requirement over those requiring less, water may move more effectively from its landing on the substrate and back into the atmosphere with herbaceous plants as the interface. In addition, higher levels of water loss provide greater water movement and increase localised cooling of the surrounding environment.

Plant selection for aesthetics

If aesthetics are important, then select plant species that will provide interest throughout the year, and consider both foliage and flowers. The period after flowering provides interest from dried flower or seed-heads, for example, *Leonotis leonurus, Agastache rugosa,* ornamental *Allium* species, and native species *Olearia axillaris.* Planting in layers, with drought tolerant (seasonally dormant) species is another approach. *Bulbine bulbosa, Senecio spathulatus,* and other short lived species can be added in with perennial species.

Plant selection for drought tolerance

Plants that come from ecosystems with shallow soils, such as rock outcrops, have been shown to both survive extended dry periods and make use of the high water available after rainfall and dry out the growing substrate. Successful species have also been shown to re-sprout after droughts, offering an 'insurance policy' if conditions are particularly harsh. These species include *Dianella revoluta, Stypandra glauca* and *Arthropodium milleflorum.*

Experience in Melbourne has shown that the succulent species *Sedum xrubrotinctum* and *Sedum pachyphyllum* were able to survive extreme dry conditions on the unirrigated shallow substrate green roof at the University of Melbourne's Burnley Campus through the summer of 2008-09. Other species that failed under the extreme conditions of 2008-09 but survived the milder 2009-10 and 2010-11 summers without irrigation were *Sedum reflexum, Sedum mexicanum, Sedum spurium* 'Schorbuser Blut'.

3.8.3 Types of green roof plans

Kleinia mandraliscae

Low-growing succulents

Succulents, particularly colourful sedums, dominate shallow substrate green roofs across temperate Europe and North America. Their low growing and/or spreading habits, great drought tolerance, seasonal flowers and contrasting foliage colours, textures and forms make them ideal candidates for green roofs. Many will benefit from some irrigation, particularly during drier months of the year. In projects with no, or minimal, irrigation, thicker-leaved succulents are the most suitable. Succulents should be planted at high density (up to 16 per square metre) to provide adequate coverage of the growing substrate and aid shading across the surface.

Lychnis coronaria var. *rosea*

Sisirhynchum bellum 'California Skies'

Herbaceous perennials

This category includes a range of non-woody plants, many with persistent roots or underground stems (such as rhizomes and stolons, etc.) that enable the plant to regrow and persist for many years. The most useful herbaceous perennials for Melbourne green roofs are those originating from dryland habitats. Flowering perennials are used mainly for display and seasonal interest, and many indigenous flowering plants used will also have significant habitat values. Ornamental grasses and grass-like plants, especially those forming upright tussocks, provide useful contrasts in texture and form and can be managed through pruning to maintain their shape and habit. Some may have high water needs over summer and large biomass forms could present a fire hazard in some locations.

Geophytes (bulbs, corms, and tubers) are another group of herbaceous perennials that can be extremely useful, particularly for seasonal interest and display. Many of the spring and autumn flowering geophytes are also summer dormant, making them particularly useful drought 'avoiders' over the warmer months of the year. Larger succulents with upright growth habits are also useful for green roofs, although their mass over time can be considerable. While many herbaceous perennials can be grown in substrate depths as little as 150 mm, irrigation will be needed for long-term success at these depths. Some caution is needed in the use of plants with vigorous rhizomes or stolons (such as some Bamboo species); they can become excessively dominant and damage green roof profile layers.

Brassica juncea

Annual and biennial plants

A range of annual and biennial plants can be used successfully on green roofs and tend to fall into two distinct groups. Quick growing annuals and ephemerals, particularly those originating from dry and arid climates, can be spectacular additions to display plantings, but will need irrigation to be sustained for longer periods. Vegetables are the other main group of annual plants used on green roofs. These require irrigation and a substrate depth of at least 200 mm. Careful plant selection and maintenance is needed to ensure annuals do not become weeds on a green roof.

Stenotaphrum secundatum 'Sir Walter'

Turf

Some green roofs are constructed specifically to support sports turf. Careful species selection is needed to ensure outcomes can be met: the surface and play requirements are much more demanding than for amenity turf.

Sports turf requires a designed soil or growing medium to ensure effective drainage and a substrate depth of at least 250 mm. It also requires regular irrigation, fertilising and mowing to maintain sward performance and health. Many facility managers seek expert advice on the use of sports turf on green roofs to ensure design outcomes and maintenance can be properly resourced and managed. On smaller scale green roofs, species with excessive vigour, such as Couch Grass *(Cynodon dactylon)* and Kikuyu *(Pennisetum clandestinum)*, should be avoided: their rhizomes can be invasive and may damage waterproofing membranes.

Cotoneaster dammeri

Small shrubs

Shrubs to one metre in height are best used in substrate depths of 250 mm or more. Small shrubs provide cover, display and habitat values, and often form the bulk of plantings used on green roofs with deep substrates. Increasing the substrate depth and irrigation will also increase the range of plants that can be used successfully. Excessively vigorous species should be avoided unless there will be sufficient maintenance to manage their growth, some low hedging plants could be in this category.

Juniperus sabina

Shrubs

Shrubs up to two metres high can be used where substrate depths are at least 600 mm. They provide screening, space definition, ground coverage and seasonal flowers. Like any plant group, shrubs require careful selection and consideration of their maintenance needs. Plants with dense, upright habits should only be used where there is minimal wind exposure and/or significant protection can be afforded to support the canopy and prevent wind forces. Hedges and screening shrubs will require regular maintenance, including pruning and removal of biomass off the roof.

Malus ioensis 'Plena'

Trees

While many small trees (to five metres) can be successfully grown on substrate depths of 600 mm, depths of 1,000 mm or greater will ensure the best outcomes are achieved. Trees are dominant elements in any landscape, and on a green roof trees will generally be stunted in height and spread, when compared to those planted at ground level. The greater the roof exposure and overall site 'hostility', the more important tree selection becomes. Trees with sparse canopies, flexible stems and high tolerance to heat are best in areas of high wind exposure, although some form of anchorage will always be needed to manage them successfully.

Table 7. Suitable plants for green roofs in Victoria

Highlighted text indicates native species. Provided as a guide only, and should not be considered as an exhaustive list or suitable for all sites.

Low growing succulents		
Type	**Examples**	
Small and/or thin leaves	*Crassula multicava* *Sedum mexicanum, S. reflexum, S. sexangulare*	
Thick leaves and/or stems	*Carpobrotus rossii, C. modestus* *Disphyma clavellatum* *Carpobrotus edulis* *Cotyledon orbiculata* *Crassula tetragona* *Kleinia mandraliscae, K. repens* *Lampranthus deltoides*	*Mesembryanthemum echinatum, M. lehmanii, M. floribundum* *Sedum nussbaumerianum* *Sedum pachyphyllum* *Sedum xrubrotinctum* *xGraptosedum* 'Bert Swanwick' *xSedeveria* 'Pat's Pink'

Herbaceous perennials		
Type	**Examples**	
Upright flowering perennials	*Brachyscome ciliaris, B. multifida* *Calocephalus citreus* *Calotis cuneifolia* *Chrysocephalum apiculatum, C. semipapposum* *Leptorhynchos tenuifolius* *Podolepis jaceoides* *Rhodanthe anthemoides* *Veronica gracilis, V. perfoliata* *Vittadinia cuneata*	*Wahlenbergia communis, W. stricta* *Xerochrysum bracteatum* *Achillea* cultivars *Agastache* species and cultivars *Euphorbia rigida, E. myrsinites* *Nepeta* cultivars *Pelargonium sidoides* *Hylotelephium 'Matrona', H.* 'Autumn Joy' *Hylotelephium cauticola* 'Ruby Glow' *S. nemorosa* cultivars
Low, spreading ground covers	*Dichondra repens* *Einadia nutans* *Eutaxia microphylla* *Grevillea lanigera* *Kennedia prostrata* *Myoporum parvifolium* *Senecio spathulatus*	*Viola hederacea* *Aptenia cordifolia* *Cerastium tomentosum* *Convolvulus sabatius* *Glechoma hederacea* *Tradescantia pallida* 'Purpurea' *Thymus pseudolanuginosus, T. serpyllum*
Geophytes (bulbs, corms, tubers, etc)	*Arthropodium milleflorum* *Bulbine bulbosa, B. crassa, B. vagans* *Pelargonium rodneyanum*	*Allium* species and cultivars *Tulbaghia violacea*
Larger succulents (upright and rosette forms)	*Aeonium arboreum* *Aeonium haworthii* *Aloe mitriformis* *Aloe* 'Gemini' *Aloe brevifolia*	*Crassula falcata, C. ovata* 'Blue Bird', *C. tetragona* *Echeveria ximbricata* *Echeveria* cultivars *Hesperaloe parviflora* *Yucca desmetiana*

Herbaceous perennials (continued)

Type	Examples	
Grasses	*Austrodanthonia caespitosa, A. setacea* *Austrostipa scabra* *Chloris truncata* *Deyeuxia quadriseta*	*Dichelachne crinita* *Orthrosanthus multiflorus* *Helictotrichon sempervirens* *Miscanthus* cultivars
Flowering plants with 'grass-like' foliage	*Anigozanthos* cultivars *Conostylis* species and cultivars *D. caerulea, Dianella revoluta, D. tasmanica* species and cultivars *Ficinia nodosa* *Lomandra micrantha, L. multifida* and cultivars *Poa hiemata*	*Stypandra glauca* *Themeda triandra* *Armeria maritima* *Sisirhynchum* cultivars *Iris unguicularis* *Liriope* species and cultivars *Ophiopogon japonicus*

Annual and biennial plants

Type	Examples	
Plants for floral display	*Calandrinia eremaea, C. polyandra* *Calendula officinalis*	*Tagetes patula, T. erecta* *Zinnia elegans*
Culinary herbs and vegetables	*Ocimum basilicum* *Petroselinum crispum* *Salvia officinalis, S.* 'Greek Skies' *Thymus vulgaris* *Origanum vulgare*	*Allium schoenoprasum* With a suitable substrate and irrigation, most vegetables that can be grown in containers should succeed on a green roof

Turf

Type	Examples	
Amenity turf	*Zoysia macrantha* *Stenotaphrum secundatum* *Zoysia* species *Festuca arundinacea*	*Festuca rubra* 'Commutata' *Poa pratensis* *Lolium perenne*
Sports turf	*Cynodon dactylon* *Pennisetum clandestinum*	*Digitaria didactyla* *Lolium perenne*

Shrubs		
Type	**Examples**	
Small shrubs (to 1 m)	*Acacia amblygona* *Correa glabra, C. reflexa, C. decumbens* and cultivars *Olearia axillaris* *Plectranthus argentatus* *Buxus sempervirens* and *B. microphylla* species and cultivars *Cotoneaster dammeri* *Erysimum xcherei* *Gaura lindheimeri* species and cultivars	*Helichrysum italicum* *Lavandula* species and cultivars *Nandina domestica* 'Nana' *Plectranthus ciliatus, P. parviflorus* *Salvia chamaedryoides, S. microphylla* species and cultivars *Santolina magonica, S. chamaecyparissus, S. neapolitana* cultivars *Teucrium marum*
Shrubs (to 2 m)	*Callistemon* 'Little John' *Correa alba* *Eremophila debilis* *Grevillea obtusifolia, G. rosmarinifolia* *Lasiopetalum behrii* *Melaleuca incana* *Westringia* species and cultivars *Cistus* species and hybrids	*Escallonia* cultivars *Juniperus horizontalis, J. sabina* *Leonotis leonurus* *Nandina domestica* *Pittosporum tobira* *Raphiolepis umbellata, R. indica* species and cultivars *Rosmarinus* species and cultivars *Viburnum tinus*

Small trees (to 5 m)		
Type	**Examples**	
Trees	*Acacia cognata* cultivars, *A. pendula, A. stenophylla* *Brachychiton rupestris* *Eucalyptus caesia 'Silver Princess', E. dolichorhyncha, E. macrocarpa, E. pauciflora* *Ficus microcarpa* var. *hillii* *Tristaniopsis laurina* *Arbutus* species and hybrids *Cercis siliquastrum* *Citrus limon*	*Cussonia paniculata* *Jacaranda mimosifolia* *Lagerstroemia indica xfauerii* cultivars *Malus ioensis* 'Plena' *Metrosideros excelsa* *Pyrus salicifolia* *Quercus ilex, Q. suber, Q. coccifera* *Geijera parviflora* *Ulmus parvifolia* *Olea europaea* 'Tolley's Upright' or 'Swan Hill' *Laurus nobilis*
Tree-like forms	*Dracaena draco*	*Yucca gigantea*

3.8.4 Green wall plant selection

Depending on the scale of the wall, plantings can range from ground covers to larger herbaceous species, shrubs and even small trees.

Plant selection should firstly consider the desired outcomes of the green wall. Certain plants will be better for aesthetic and landscape design values, drought tolerance, water purifying, air filtering or habitat provision. It is important to realise that plant growth form, sun and shade exposure as well as wind exposure, is notably different on vertical surfaces compared to a roof or at ground level. Obtaining specialised advice and visiting existing green walls will improve understanding of which species will be best suited.

The selection of species will also depend on the climatic conditions on-site. Consider the level of natural or artificial light available. (Be aware that plant selection will require an understanding of 'photosynthetically active radiation', the type of light that a plant responds to, rather than simply a measure of how the human eye perceives brightness). Select very shade tolerant species to suit the lowest light conditions. In highly exposed locations, select robust species that can tolerate sun and wind. Look for species that have shallow, fibrous root systems to promote strong anchorage in the limited volume of growing medium available. Recognise that the tops, corners and sides of the wall will have greater wind exposure. Investigate species that thrive in exposed conditions, such as coastal cliffs or inland rocky outcrops.

Larger plants may grow to shade others, so this must also be considered in the placement of species. External green walls are often exposed to strong and frequent wind. Vigorous growth increases maintenance requirements and slow growing plants are often preferred. However, vigorous species can be used to create protected niches for the inclusion of sensitive species in high exposure areas. This can help provide light or shade for other species, wind protection or humidity conservation. Consideration of where each species will be placed in relation to others (the array of plants) helps develop a working artificial ecology on the wall. Understanding how the ecology will morph as the plants mature is important, as niches will evolve beneath, next to and above certain species.

Plant selection must be matched to the particular green wall system and technology that is being installed. Not all species will grow well in each system. Some systems might cater well for terrestrial plant species (and need an appropriate growing substrate); others have an irrigation/fertigation or growing media system that favours epiphytic/lithophytic species (plants that do not require soil for growing and can exist on branches or rock surfaces).

Water requirements can be minimised by selecting species that are low water users. Recognise that more water may be available toward the base of a green wall system, so species should be selected and positioned on the wall with moisture gradients in mind. If the system recycles water, species selection may have to cater for elevated salt levels and amended pH levels.

Table 8. Suitable plants for green walls in Victoria

Shrubs	*Correa* cultivars *Escallonia* cultivars *Ficus* species *Metrosideros* excelsa 'Nana'
Evergreen herbaceous perennials	*Spathiphyllum* cultivars *Philodendron* 'Winterbourn' and 'Xanadu' *Monstera* species *Liriope* species and cultivars *Schleffera* species *Viola* species *Erigeron karvinskianus* *Chlorophytum comosum* *Peperomia* species *Plectranthus* species *Rhipsalis* species *Bromeliad* species Orchid species
Herbaceous ground covers	*Epipremnum species* *Plectranthus ciliatus*
Ferns	*Asplenium* species *Blechnum* species *Davallia pyxidata* *Humata tyermanii* *Nephrolepis* species
Grass-like foliage forms	*Acorus gramineus* cultivars *Bulbine* species *Ficinia nodosa* *Dianella* species and cultivars *Dietes* species *Lomandra* species and cultivars *Ophiopogon japonicus*
Lilies & irises	*Arthropodium cirrhatum* 'Te Puna' and 'Parnel' *Arthropodium* species and cultivars *Neomarica gracilis* *Patersonia occidentalis*

3.8.5 Green facade plant selection

Plant selection for green facades is strongly influenced by the mode or method of climbing plant attachment. Most climbing plants attach themselves to a surface or structure in one of two ways (see Figure 16):

- Self-clinging – attachment through adhesive suckers, disks or adventitious roots. These climbers then form a self-supporting vegetation layer on a solid wall or surface.
- Twining and tendrils – attachment by twining stems or by hooking and clasping tendrils (modified leaf/stem organs). These climbers require a specialised support system and can produce both upward and cascading (or trailing) stems.

Another group of climbing plants have a scrambling habit and are known as scandent shrubs. These have no direct means of attachment and need to be tied and managed onto the structure that supports them. They may be vigorous and woody in their growth habit, which can make them difficult to be sustained on a structure without significant pruning and maintenance (such as *Bouganvillea glabra*).

Self-clinging climbers create green facades that can provide effective and long-term cover but may not be suited for buildings where the surface fabric is in poor repair. Many self-clinging climbers will mark a wall surface through their attachment, however this is rarely seen because of the foliage cover. Excessively vigorous species such as Common Ivy (*Hedera helix*) should be avoided and regular pruning will always be necessary to maintain suitable plant growth, form and size.

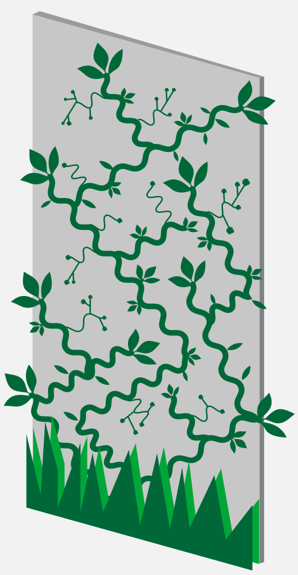
Twining climbers require a support system, such as cable or trellis, to support their growth habit. These supports may be attached to the building, or mounted independently. Plant selection needs to consider the available space for plant growth as the distance between the wall and the support structure will impact on plant performance and climate control.

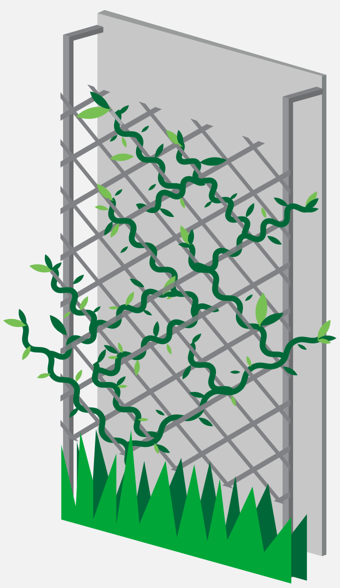
Climatic factors

Species tolerant of low light are required for deeply shaded urban 'canyons' while high light tolerance is needed in exposed and elevated settings. Generally, direct sunlight is considered to be four hours of sun per day and most species will require at least some direct sunlight to grow.

Facades can be established in areas of full shade, but the range of species that will grow in these conditions is limited. Facades at high elevation, in coastal areas or urban street canyons can be exposed to strong and frequent wind. Some plant species, twining climbers in particular, are more tolerant of wind and more mature plants tend to be more resilient in these environments. Self-clinging facades may be pulled away from the wall in very windy conditions. Small-leafed species with strongly attached foliage may be more suitable on sites prone to strong blasts of wind: large foliage may be stripped or shredded in these conditions.

Figure 16. Climbing plants used on green facades have different modes of attachment





Long-term maintenance

The plant's lifecycle and growth rate will affect the time it takes for the facade to establish and the amount of ongoing maintenance required. Consider the mature size of the species as well as the level of foliage coverage required. Many climbing species exhibit early rapid growth but slower mature growth rates. Some green facade plants, such as Creeping Fig (*Ficus pumila*), require rejuvenation pruning to ensure juvenile foliage is maintained. With this species, adult foliage grows horizontally, does not attach directly to the building and creates a deeper, denser canopy of woody stems. While this may provide effective shading and create an insulating layer of air between the foliage and the building, it is inherently unstable because this canopy is not directly attached to the building. Woody climbers need careful selection as maintenance needs often increase over time, as stems grow larger and thicker and the plant increases in size: for example, *Wisteria sinensis* and *Vitis vinifera*.

Climbing plant species ideal for screening will have multiple features including:

- retention of lower foliage
- high shoot density
- pendulous leading shoots
- tolerance of and recovery from severe pruning (rejuvenation)
- longevity
- reliable growth rate

These features contribute to the production of consistent and uniform vegetative cover.

In their natural habitat, many climbing plants grow upwards towards the light, by twining or scrambling, and over time, they lose foliage cover at their base. Such species may be unsuitable as screening plants in the long term, if they do not respond to hard (rejuvenation) pruning to encourage new basal shoots, such as *Pandorea jasminoides* (Bower Vine).

The following table indicates some common climbing plants used in Victoria, how they attach, their ability to cover an area of facade – how well they screen (high to low cover) and how fast they grow (this indicates how much maintenance they require) – and their light tolerance. Average in the table indicates that they are not known to be particularly needy of high light nor particularly tolerant of low light. Note that the mature size will be affected by the soil volume available.

Table 9. Suitable plants for green facades in Victoria

Species	Type	Screening and Growth Rate	Light Tolerance
Akebia quinata	Twining	Medium cover and growth rate	Average
Aphanopetalum resinosum	Twining	Medium cover and growth rate	Average
Cissus antarctica	Tendril	High cover and growth rate	Tolerates low light
Clematis aristata	Twining	Medium cover and growth rate	Tolerates low light
Clematis armandii	Twining	Low cover and growth rate	Average
*Clematis montana**	Twining	Low cover and growth rate	Average
Distichtus buccinatoria	Tendril	High cover and medium growth rate	Requires high light
Ficus pumila	Self-clinger	High cover and medium growth rate	Requires high light
Hibbertia scandens	Twining	Medium cover and growth rate	Requires high light
Muehlenbeckia complexa	Twining	High cover and growth rate	Average
Kennedia rubicunda	Twining	Medium cover and high growth rate	Requires high light
Pandorea pandorana	Twining	High cover and growth rate	Average
Pandorea jasminoides	Twining	Medium cover and growth rate	Average
*Parthenocissus quinquefolia**	Self-clinger	High cover and medium growth rate	Average
*Parthenocissus tricuspidata**	Self-clinger	High cover and growth rate	Requires high light
Podranea ricasoliana	Scandent shrub	High cover and growth rate	Requires high light
*Vitis vinifera**	Tendril	Medium cover and growth rate	Requires high light
Trachelospermum jasminoides	Twining	High cover and medium growth rate	Average
Wisteria sinensis	Twining	Low cover and high growth rate	Requires high light

*deciduous

3.9 Designing for plant establishment

Good plant establishment is critical for the long-term health and performance of plantings in green roofs, walls and facades. In the design stage this includes consideration of multiple factors, including:

Use of high quality planting stock	Stock that is too advanced or has overgrown its containers has high water needs and can be slow to establish on a site. Planting stock should be of an appropriate size to achieve the aims of the project, in terms of growth rate and coverage. It should also be completely free of weeds, pests and disease.
Plant production in a high quality growing medium	In some cases using a medium with similar physical properties to the final growing substrate will assist in promoting plant growth.
Working in with seasonal conditions	In most situations planting is best completed between autumn and early spring. This will assist plant establishment and growth, well before the warmer and drier conditions of summer.
Establishment irrigation	Allowance should be made for suitable irrigation, usually for a minimum of six months, to avoid moisture stress and to promote plant growth across the site.
Weed control	During establishment, weeds will compete vigorously with designed plantings on a green roof, wall or facade. Weeds must be controlled until the plantings achieve the desired growth rates and/or coverage.

Further information about vegetation can be found in Chapters 5, 6 and 7.

Plants will often establish best on-site, and should not be planted when they are large as they will grow to cover the site over time

High quality plants should be sourced, ideally grown in a medium with similar properties to the growing substrate they will be planted into


Construction of a green roof, Docklands. Image: ASPECT Studios

4. BUILDING & INSTALLATION

GENERAL ADVICE

This chapter provides general advice about building green roofs, walls and facades, including occupational health and safety, insurance considerations and what to expect at project completion on a large-scale job which has a project manager and several consultants.

4.1 Occupational Health and Safety

As for all construction work, the construction (and maintenance) of green roofs, walls and facades is subject to the Victorian *Occupational Health and Safety Act 2004*. This Act governs all Victorian OH&S laws and codes of practice and sets out the key principles, duties and rights in relation to OH&S. The hierarchy of regulation in Victoria is shown in the diagram below.

Figure 17. Occupational Health and Safety legislative framework in Victoria

Victorian Occupational Health and Safety Act 2004			
Occupational Health and Safety Regulations 2007			
Compliance Codes	Worksafe Victoria Positions	OHS Compliance Framework	WorkSafe Victoria Policies

Guidance materials available from WorkSafe Victoria inform duty holders on how to comply with Victorian OH&S legislation. Consultants can also provide advice on ensuring OH&S requirements are met.

Note that National Workplace Health and Safety codes and guidance materials have no legal status in Victoria.

High-risk construction work

Some construction projects involve high-risk construction work and additional regulations govern management and procedures in such cases. High-risk construction work is of particular relevance to the design, construction and installation of green roofs, walls and facades as it is likely to involve work:

- where there is a risk of a person falling more than two metres
- on or near electrical installations or services, for example, the possibility of drilling into a wall containing live electrical wiring
- at a workplace where there is any movement of powered mobile plant, for example, working in an area of a construction site with moving skid steer loaders, telehandlers, backhoes, mobile cranes or trucks

Materials handling and storage

As on any building site, the materials used to construct a green roof, wall or facade should be delivered in a timely way to meet construction schedules. Consideration must be given to where materials will be unloaded and stored and how they will be moved to and from site. Secure storage and safe handling of materials on-site may be needed. For safety reasons, a roof must not be used for materials storage when a green roof is being constructed, as it is a building site and must be managed for weight, access, security of materials and safe movement of personnel.

Working at heights

The design and installation of all green roofs – and many green walls and facades – involves work at heights. The associated risks and responsibilities must be managed through a combination of training and safety features on the site including the use of barricades, railings, or other fall arrest systems, such as ropes and harnesses.

Consult the WorkSafe Victoria Compliance Code 'Preventing Falls in General Construction' with regard to specific OH&S issues associated with working at heights and management solutions. Wherever possible, the risks and hazards of working at heights should be removed or reduced and the design team must consider these as part of project planning.

Safety in Design legislation

A Safety in Design risk assessment or workshop should be undertaken with the design and construction team/s to identify risks and determine the actions necessary to remove or reduce the likelihood of occurrence and severity of these risks.

4.2 Insurance and system warranties

The scale, complexity and overall cost of a green roof, wall or facade will determine whether insurance and warranties are relevant. Almost all professionally-installed projects will include them; smaller, DIY projects may not.

Until the local industry is further developed, it may be beneficial to consider insurance companies with a global reach that gives them relevant understanding and experience. Commercial insurer FM Global provides useful specifications for green roof design, installation and maintenance that can be used as a risk management tool during design and planning.

The warranty for a green roof, wall or facade will be straightforward if an established installation company, or a contractor licensed by that company, installs a proprietary system. Under these circumstances, the parent company should provide a warranty against failure of any or all of the components. Custom-built green roofs, walls or facades, with mix-and-match components, or multiple providers, may not be as straightforward to warrant or insure.

Waterproofing is more likely to be warranted separately if it is installed by a third party. However, the company supplying and/or installing the waterproofing may not take responsibility for breaches of the membrane that occur after it is certified as watertight, if they have no ongoing involvement with the project. Ensure there is clarity around the warranty conditions.

The client usually has the option to negotiate a defects liability period with the contractor. The contractor will be responsible for repair of defects that appear within an agreed period of time after project completion and may have responsibility for defective work beyond the product warranty period. Warranties may be waived if a DIY approach is undertaken with the product.

4.3 Project completion

Contractors and sub-contractors must provide necessary certifications at the completion of their work. At handover, the project manager will provide documentation of all necessary inspections and relevant certifications to the building owner. These should include:

- warranty on waterproofing
- drawing showing 'as built' planting (the actual planting may have varied from the design drawings)
- certificate of completion from a registered building inspector
- certificate of electrical safety from a licensed electrician (if relevant)
- certificate of occupancy (if relevant) from a building inspector/local council – this will relate mainly to safety and access requirements, including step heights and access points

Operational manuals must be handed over to the owners and/or contractors who will be engaged in operation or maintenance of the site. This must include the setting of an agreed time for any initial or ongoing training in the operation of systems installed on the site. Provision of funds for such training should be included as a contingency item in the budget during the design phase.

Maintenance or operational manuals may include:

- a planting maintenance plan
- an irrigation operations manual
- schedules for cyclical maintenance

Maintenance is discussed in more detail in Chapter 8.


Green roof at the Museum of Old and New Art, Hobart. Image: Pad Creations

5. BUILDING & INSTALLATION

GREEN ROOFS

Once the planning and design stages of a green roof are complete, well-planned construction can deliver the project objectives. This chapter provides specific information about how to construct a green roof.

Constructing green roofs

Green roofs are built up as a series of layers, with each performing a specific function. The most typical build-up is shown below and includes:

- the roof structure (roof deck)
- waterproofing layer
- protection layers (including the option of a protection mat and/or root barrier layer)
- drainage layer
- filter sheet
- growing substrate
- vegetation

The role of each of these components is outlined in the following pages. This chapter also covers other elements that may be incorporated into a green roof system, or are relevant to construction of a green roof, such as:

- leak detection systems
- thermal insulation
- irrigation
- greening in windy environments or on a pitched roof
- hard landscaping elements

Specialists in green roof design and installation can provide advice on the most suitable system and the most appropriate construction approach.

Figure 18. Layers of green

A green roof contains plants that are grown in a layer of substrate varying in depth from a few centimetres to well over a metre. The growing substrate is usually composed of a high proportion of mineral particles with a long lifespan, with a small proportion of organic matter. A filter sheet retains the substrate and prevents washout into the underlying drainage layer. A protection mat and a root barrier may be installed to prevent damage to the underlying waterproofing membrane that covers the roof deck.

5.1 Roof deck

Green roofs can be installed on roofs made of concrete, timber, sheet metal (usually clip-lock, or corrugated galvanised steel) and a range of other materials. However, it may be difficult to obtain insurance for green roofs installed on roof decks made from materials other than structural concrete or metal. Green roofs are most commonly installed on concrete roof decks because of structural integrity, ease of design, durability and amenity when complete. See Chapter 5.12 Slopes and wind protection for specific considerations relating to pitched roofs.

Greening a tiled roof requires special treatment. A green roof cannot be installed directly on a tiled roof. If the building has adequate load capacity, or if structural reinforcement and a support system can be incorporated into the design, a green roof may be constructed as a self-contained waterproof module that sits above the existing roof. Drainage from the green roof must connect directly into the lower level roof drainage system. It may be more economical to replace the roof to make it suitable for a green roof.

The components installed on the roof deck will be either loose-laid over the roof surface or installed as modules that connect together to form a continuous effect. Individual containers that are separately placed on a roof deck are considered a roof garden rather than a green roof, and because they do not cover a significant proportion of the roof they do not provide most of the benefits associated with green roofs.

It may be necessary to remove or relocate existing infrastructure on roof decks, or the green roof can be built around the equipment.

Roof decks can be flat or pitched, and they are commonly made of metal or concrete

5.2 Waterproofing

A watertight roof is critical to successful green roof construction. While some roofs are intrinsically waterproof when built, most will require some form of treatment to prevent water entry into the building. Waterproofing treatment must provide a strong but flexible layer that allows expansion under physical or thermal movements of the building structure, without compromising watertightness. Vegetation generally should not be installed over areas such as expansion joints, where regular inspection of the waterproofing will be necessary.

Advice should be sought from a specialist waterproofing manufacturer to find the most suitable type of waterproofing treatment for the roof structure and the proposed green roof design. The manufacturing and installation of waterproofing membranes should comply with Australian Standards (see Chapter 6.2 for more information).

In Australia, waterproofing is likely to be installed by a third party waterproofing contractor. The involvement of an independent contractor means that a clear agreement between all parties must be established for responsibility of the waterproofing membrane once it has been installed and certified as watertight. An independent leak detection specialist should test the waterproofing after its installation, and again after the green roof build-up is installed, prior to handover (see also Chapter 4.3).

The following tables contrast the two major types of waterproofing – liquid applied treatments and preformed sheets:

- Liquid applied treatments can be composed of bitumen emulsions, modified bitumen, polymer cement systems, polyurethane, polyurethane modified acrylic, acrylic or two-part polyurethane hybrid elastomers that require mixing prior to application.
- Preformed sheets are asphalt-based or comprised of thermosetting polymers or thermoplastic polymers.

Preformed waterproofing may suit green roofs with gentle slopes and large uninterrupted areas. A green roof with many fixings onto the roof deck or penetrations, such as for lighting, power or ventilation, may be more suited to liquid applied waterproofing that is sprayed on or rolled on to form a cohesive single layer.

Waterproofing membranes must be protected from physical and chemical damage. This includes cuts and tears, the action of invasive roots and rhizomes, and exposure to the elements. All membranes will become brittle over time, and this is accelerated by exposure to cold, heat and UV rays from sunlight. A green roof will shield the membrane from damage and can significantly lengthen its life. Some preformed membranes have a surface coating that provides additional protection.

Ensure that the waterproofing material is certified root resistant, suitable for the substrate, and installed by experienced, trained and certified professionals.

Root resistance may be built into waterproofing membranes either by the addition of root-inhibiting chemical treatments, or because the composition of the membrane provides an impenetrable barrier to root growth. Root resistant waterproofing is quicker to install than separate waterproofing and root barrier layers, but can be more costly. Examples include certain types of ethylene propylene diene monomer thermosetting, thermoplastic PVC and thermoplastic polyolefin membranes; however, the root-resistance of a product must be confirmed with the manufacturer, with certification provided.

Table 10. Common waterproofing treatments

Liquid applied waterproofing treatments		
Suitability	**Advantages**	**Disadvantages**
Complex designs with many upstands[1], corners or curves Roofs where access for sheet installation is difficult	• Seamless • Often trafficable • Flexible and capable of elongation • Easy to apply • Tolerant of some degree of surface imperfection • Easily repaired by re-application over breaches • Bonded to the roof	• Pin-holes may develop on poorly prepared roof surfaces[2] • Solvent-based treatments become brittle over time and with exposure to sunlight and high temperatures • Root resistance • Not easy to ensure uniformity of thickness • Not recommended for use in permanently wet conditions, as they absorb moisture and soften over time

Preformed waterproofing sheets			
Membrane composition	**Application methods**	**Advantages**	**Disadvantages**
Asphalt-based	Loose-laid Fully bonded "torch-down" Partly bonded	• Loose-laid membranes quick to install compared to bonded. • Fully bonded more resistant to wind uplift than partly bonded. • Fully bonded recommended by some green roof installers and lower risk of uplift makes insurance easier to obtain • Easier to locate leaks with precision with fully bonded membranes. • More resistant to wind uplift than loose-laid.	• Loose-laid not recommended if high risk of wind uplift • Soft structure means membranes are usually not trafficable, UV resistant or root-resistant. • Prone to failure and root penetration along seams due to softness of composition • Installation requires a high degree of skill to ensure high quality detailing of seams and around upstands[1]. • Become brittle over time through exposure to sunlight, heat and cold.
Thermo-plastic	Fully bonded	• UV stable and weatherproof • Seams can be welded with heat or solvent[3]; or heat only[4] • Bonding of membrane to the roof with heat, solvent, water-based adhesive, or tape reduces risk of wind uplift • PVC membranes are breathable, and well suited for bonding to the roof deck with glue or tape adhesives • PVC, thermoplastic polyolefin, ethylene vinyl acetate and ethylene butyl acrylate membranes are likely to be classified as root resistant: check manufacturer's specifications • Mechanical fastening to the roof deck may be suitable for some applications	• With classes of membrane other than PVC, condensation of moisture may soften glue or adhesive tapes used to attach membrane to the roof deck, increasing risk of wind uplift
Thermo-setting	Fully bonded	• Ethylene propylene diene monomer (EPDM) and Butanoyl® membranes are likely to be classified as root resistant: check manufacturer's specifications • UV stable and weatherproof: long lifespan • Bonding with glue or adhesive tape reduces risk of wind uplift	• Condensation of moisture may soften glue or adhesive tapes used to bond waterproofing to the roof deck • Carbon content of EPDM/Butynol® membranes makes them intrinsically electrically conductive and therefore unsuitable for electronic leak detection

[1] Upstands are structural penetrations from the roof such as vent pipes that will need to have the waterproofing layer brought up ('dressed up') around them to terminate above the level of the substrate.
[2] Note that the waterproofing consultant must certify that the roof is fit to receive the membrane prior to installation.
[3] Thermoplastic polymers composed of chlorinated polyethylene, polyvinyl chloride (PVC), thermoplastic polyolefin, ethylene vinyl acetate and ethylene butyl acrylate.
[4] Thermoplastic polymers composed of ketone ethylene ester.

5.3 Protection layers

Root barrier

Root barriers are often used in green roofs to provide some protection to the waterproofing from invasive stolons, rhizomes and from woody roots from trees and shrubs. The most common root barriers used are thin polyethylene sheets, laid over the waterproofing membrane. These may not be required if the waterproof membrane is certified as root-resistant. Thicker, welded root barriers will be needed for green roofs involving trees, bamboo or other vigorous, spreading grasses.

It is important to check the compatibility of the product with bitumen and polystyrene, especially where there is direct contact with a bitumen-based waterproofing or polystyrene insulation. The root barrier must also be resistant to the humic acids produced when plants decompose.

Separation sheets are sometimes installed between the waterproofing and root barrier to provide additional protection and separate materials that are not compatible. These are typically HDPE sheets laid directly on the waterproofing.

Protection mat

Protection mats or boards are used to protect the waterproof membrane from damage following installation. The most common materials used are water-permeable, hard wearing and dense synthetic fibres, polyester and polypropylene.

Protection matting is installed directly on the waterproofing layer (for root-resistant membranes) or atop the installed root barrier layer, providing further (uncertified) protection against root penetration and doubling as a separation sheet. The protection matting may provide some noise-absorbing capability. It can add to water retention on the roof, although the amount varies (from 3 l/m^2 to 12 l/m^2) and is only really useful on slopes below 15 degrees. A range of different products are available, reflecting the required functions, and apart from the material itself vary according to thickness (3 mm to 20 mm), fibre density and mass (320 g/m^2 to 1500 g/m^2).

Protection mat sheeting should be installed with overlaps of 100 mm and some products have rubber backing that requires gluing in situ. The product should extend 150 mm above the finished surface of all upstands (such as vent pipes, chimneys and other roof penetrations) to ensure complete roof protection.

Plant roots can be very destructive, as shown by this image of tree roots causing severe cracks in bitumen paving. A root barrier on a green roof can protect the underlying layers

A protection mat is laid to protect the waterproofing layer on a green roof

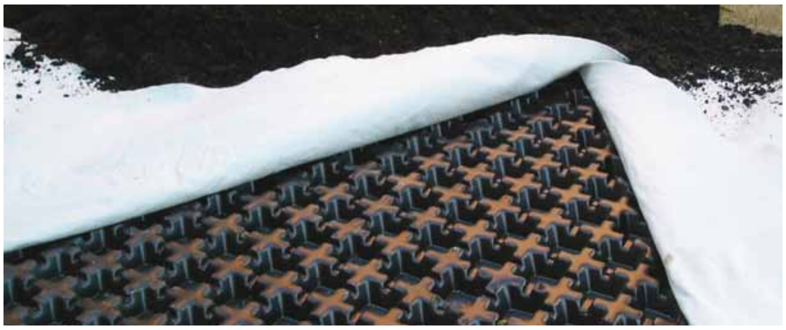
5.4 Drainage layer

Good drainage is critical for green roofs and ensures that large amounts of water are not retained on the roof, compromising both the structural integrity of the building and plant health through waterlogging and oxygen-depleted substrates. Sub-surface run-off must drain efficiently from the substrate, into the drainage layer, off the roof surface, and into drains to the stormwater or rainwater collection. The growing substrate must be kept separate from the drainage layer with a filter sheet.

Older green roofs often used a permeable layer of rock aggregate (such as scoria or gravel) for drainage. The clay and silt content of materials used in a rock aggregate drainage layer should be ≤10 per cent by mass. The rock aggregate should also have a suitable pH and be low in soluble salts to ensure plant growth is not adversely affected. This form of drainage is heavy and does not allow for air pruning of roots, which is now achieved with plastic drainage cells. However, in some situations, rock aggregate drainage does a better job controlling peak flow.

On modern, lightweight, green roofs, plastic drainage sheets or boards are the preferred drainage materials. Plastic drainage layers may be rigid, open mesh structures that allow unrestricted drainage of water, or they may have a cup-style, 'egg carton' design that enables water to be stored at the base of the profile (see image below). The advantage of the latter is that water can be stored and used later by the plant. The volume of water that can be stored varies with each product and the size and packing density of the cells.

Drainage is installed as a continuous layer over the entire surface of the green roof. Cup-style drainage sheets should be overlapped to eliminate the possibility of gaps being created between sheets. Other plastic drainage types should have adjacent sheets butted together. Very rigid drainage layers should be installed in trafficable areas of the green roof to avoid compression of the layer.



An eggcup-shaped drainage layer retains some water. Image: KHD Landscaping Engineering Solutions

5.5 Filter sheet

A filter sheet acts to retain the growing substrate, by preventing wash-through of the substrate particles into the underlying layers, and to prevent clogging of holes in the drainage layer. Filter fabric is sometimes referred to as geotextile fabric.

Considerations in the selection and use of filter sheets include:

- the expected flow rate of water as it drains through the system
- substrate type – if components of the substrate have sharp edges, the filter sheet should be strong
- vegetation type – the filter sheet must allow penetration of roots, and certain roots will be more or less aggressive (for example, herbs versus trees roots)

The filter sheet can be either a woven or non-woven material. A non-woven material is preferable as it is more resistant to root penetration and can sometimes be used as a root barrier system. The filter sheet is not weatherproof and should not be exposed to sunlight for any length of time, and it should therefore be laid immediately prior to the installation of growing substrate. At boundaries or edges of planting beds, the filter sheet should be installed with upturns to at least the same height as the top of the growing substrate (see image below).

A layer of filter sheet will prevent substrate dropping into the drainage layer. Enough filter sheet is set down over the roof so that at the vertical edges of the planting beds the sheet will be the same height as the substrate

5.6 Growing substrate

The growing substrate supplies water and nutrients to plant roots, ensures gas exchange at the roots and provides anchorage to support plants.

Growing substrates for green roofs are typically composed of a mix of inorganic (mineral) and organic components. They can include scoria, ash, pumice, sand, coir, pine bark, porous, chemically inert foams and even recycled materials such as crushed bricks, and roof tiles. Organic matter is usually kept to a low proportion (typically 20 per cent or less) because it has a relatively short lifespan, degrading and slumping over time, and may become water repellent and difficult to re-wet if it dries out. The physical and chemical properties of the substrate mix, together with its depth and total volume, influences what vegetation can be supported on the green roof.

A substrate should:

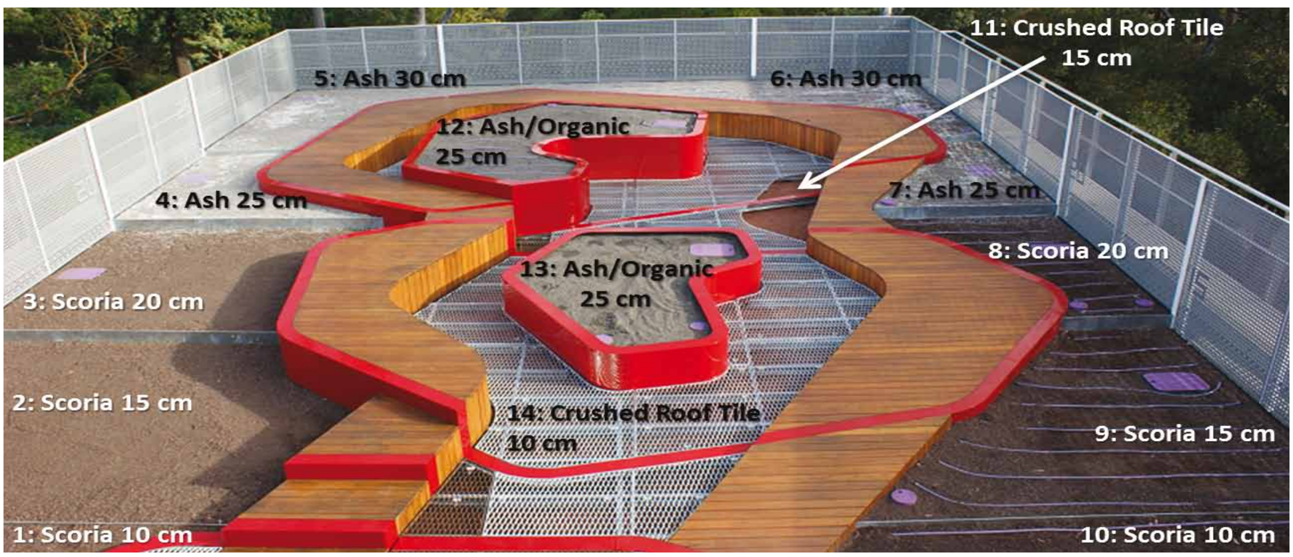
- have a known saturated weight loading, that forms part of the structural load capacity of the roof; this is referred to as the saturated bulk density
- drain freely, to reduce waterlogging and prevent inundation during heavy rain, but also retain adequate water to sustain plant growth outside of heavy rain events
- be stable over time, usually achieved by using a high proportion of mineral components and a lower proportion of organic components.

Soil is generally not used on green roofs, as its properties will be less well known compared to an engineered substrate, and therefore its longevity and suitability is harder to judge. Also, silt particles from soil can clog filter sheets and cause drainage problems.

Installers of green roof systems will be able to arrange the supply of a suitable substrate mix. Appendix A provides more information on substrate characteristics.

Transport and installation of growing substrates requires consideration in the pre-construction planning process. Most can be installed by either lifting bulker bags by crane or 'blowing' from a truck-mounted hopper, although each project will have its own specific considerations. See the Substrate Installation box following for more on installation.

A range of mineral and sheet mulches can be used successfully on green roofs but need to be considered carefully. Organic mulches, particularly fine materials, are generally unsuitable for use on green roofs as they can be easily blown off the roof, degrade rapidly, block drains, or create a fire risk in hot dry conditions. The saturated bulk density of any proposed mulch layer must be included in the weight loading calculations for the green roof build-up.



The University of Melbourne's Burnley campus has a demonstration green roof with four distinct growing substrates. These are based on recycled crushed roof tile; bottom ash from coal-fired power stations in NSW; scoria quarried locally to the west of Melbourne; and an ash-based mix with a high proportion of composted pine bark. Substrates have been installed at different depths to compare the effects on plant growth

Substrate installation

On large green roof projects, growing substrates can be installed by crane or by 'blower'. Substrate may be delivered in multiple bulker bags, typically of one cubic metre capacity, although a larger crane lifting bags of greater volume may be possible if site access permits. Care must be exercised in point loading of substrate on to the roof and movement across the roof (see Chapter 4.1).

'Blowing' a substrate involves the use of a compressor pump and hose to blow the substrate up to the roof. Sometimes substrates that are 'blown' onto a roof will have altered properties (due to finer particles aggregating during the process) and may need re-mixing on the roof to ensure success.

Growing substrate should be delivered before the day it is to be installed and stored as closely as possible to the crane, with clear access for the forklift or other machinery that will transport it to the crane lifting point. Growing substrates should be installed with minimal handling and be 'moist' to reduce the release of fine particles into the air. Appropriate personal protective equipment should be worn: gloves, dust filter masks, safety glasses and hardhat.

Bulker bags of substrate moved around the site, at ground level, prior to being lifted by crane at the demonstration roof at The University of Melbourne's Burnley campus

Substrate was blown onto the green roof in the City of Monash, Glen Waverley. Image Junglefy

5.7 Vegetation

A range of planting stock can be used for green roofs, including seed, cuttings, seedlings, tubestock and larger containerised plants. See Chapter 3 for information on species selection.

Planting is best completed in autumn and winter to assist plant establishment before summer. Irrigation should be provided while the plants establish. Depending on the time of year and rainfall, establishment irrigation could be required for up to six months.

It is helpful to acquire container-grown nursery plants that have been grown in the substrate they are to be planted into; otherwise, reduce the amount of potting mix held around the roots when transplanting into the green roof.

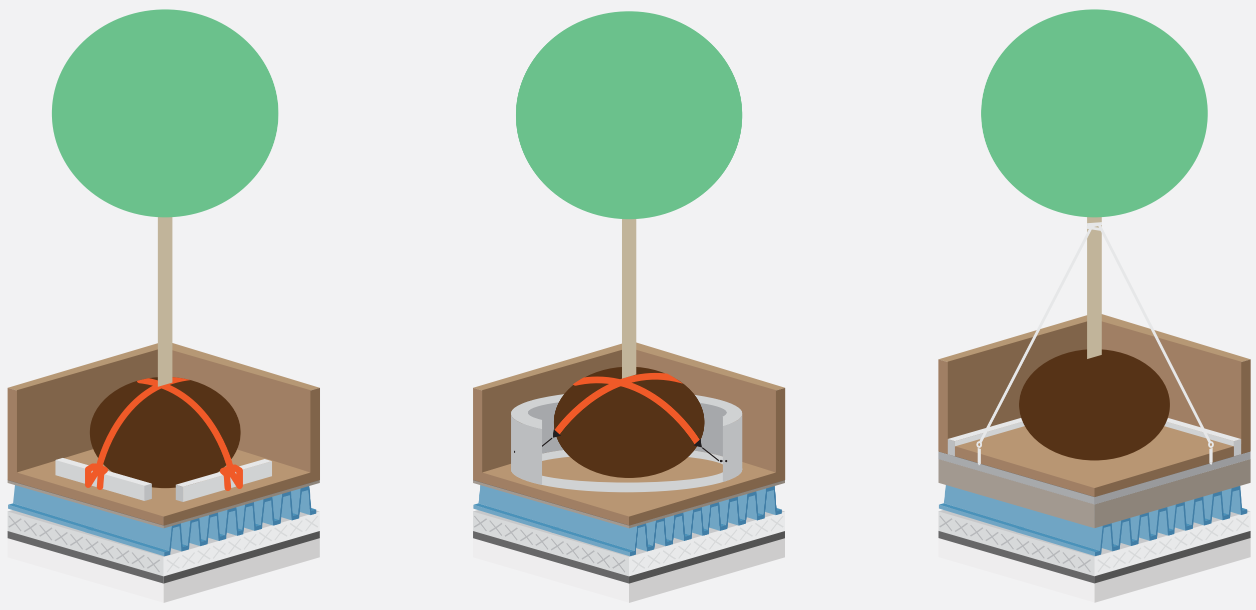
Controlled release fertiliser (CRF) can be added to the growing substrate or applied after planting is completed (top dressing). Careful consideration of rates and application methods is needed to ensure proper distribution and to limit any rapid discharge of nutrients (more information on plant nutrition is provided in Chapter 8).

Trees planted on green roofs will require a deep substrate as well as anchorage to prevent wind-throw. Various anchorage systems are available as illustrated in Figure 19. Tree bracings must be checked regularly to ensure they are functioning as specified, and not causing damage to the tree. Trees will require construction of a tree 'pit' in the substrate to house the tree roots: this needs to be deep and wide enough for lateral root growth to ensure tree stability. Consult an arborist for specialist advice.

Contract grown plants

Plants can be sourced from retail nurseries or grown at home for small projects. Generally, plants for larger projects will be grown to a contract with a wholesale nursery. Contract growing lead times may range from several months to more than a year, depending on the type of vegetation that is required. The growing contract will specify a date for completion and delivery of plants. It should outline the terms and conditions of a further holding period, for instance, if the planting date is postponed because of delays in construction. Ensure plants purchased are weed and pest free – look for nurseries with good hygiene. If in doubt, remove the top centimetre of growing medium to reduce the weed seed bank.

Figure 19. Tree anchoring systems



5.8 Thermal insulation

In some cases, a green roof may include thermal insulation, typically a layer of extruded polystyrene. While this can be positioned below the roof deck, installation above the waterproofing (known as an inverted green roof) is preferred, as it further protects the membrane from condensation and physical damage. Advice should be sought from a building energy consultant to establish the value of additional insulation, considering the insulating properties of the green roof assembly, substrate and vegetation. Research has been conducted into green roof insulation values in Adelaide and can be found at the *Building Innovation Fund* website of the South Australian Government.

5.9 Leak detection

Leak detection is carried out when the waterproofing installation is complete. There are three methods typically used for testing the effectiveness of the waterproofing layer on green roofs:

Electrical field vector mapping (EFVM)®	Is suitable for electrically conductive and electrically grounded roof decks such as steel and reinforced concrete roofs. EFVM® can be used on wooden roofs or precast concrete slab roofs if a conductive layer of metal foil or mesh is applied to the roof deck before the waterproofing layer is installed. The decision to use EFVM® must therefore be made at the design stage.
Destructive testing	Is used for preformed waterproofing membranes. The membrane is perforated at the lowest parts of the roof deck to check for the presence of any water beneath the membrane. The penetrations made through the waterproofing must then be repaired to restore the membrane's integrity. Destructive testing may be the only method that can be used on older existing green roofs. For new projects, EFVM® should be considered during design, as it is simpler, safer and non-destructive of the waterproofing system.
Flood testing	Is suitable only for flat roofs with slopes of up to 2 per cent. Flood testing involves temporarily blocking the roof drains and flooding the roof membrane with a known depth of water for a set period of time. The weight loading of the roof must be checked against the weight of water that will sit on the roof during the test. This ensures that the structural integrity of the building is not compromised.

It is advisable to perform an additional leak test prior to installation of the growing substrate if significant time has elapsed since the waterproofing was completed, or if there has been construction activity or other traffic on the roof. The repair of leaks presents a greater challenge once the growing substrate and vegetation are installed. However, EFVM® leak detection should be performed at this time (project completion). It may also be carried out prior to the expiration of membrane warranties.

Electrical field vector mapping: An electric field is created by applying water on the surface of the membrane and using the water as a conductive medium. The EFVM® equipment delivers a low voltage pulsating electrical charge between the non-conductive waterproofing membrane and the conductive structural deck. Source: International Leak Detection Australia

5.10 Irrigation

An irrigation system is highly advisable on green roofs: to extend plant species selection options, to improve plant growth rates and increase long-term vegetation success – thereby ensuring aesthetic and environmental (such as building cooling, stormwater reduction) outcomes can be achieved. Planning for irrigation on a green roof should consider the site layout and conditions (access, exposure), type of plants, climate and water supply issues (pressure, quality, etc.). Substrate properties and depth are also important as they influence water infiltration, holding capacity and drainage. In most cases, irrigation design will be heavily influenced by the nature of the water supply resource (for example, harvested vs. potable water) and a water budget should be used to guide not just irrigation but also plant selection (see Chapter 3). In larger green roof projects, irrigation is best undertaken by a specialist consultant to guide system design, component selection, installation and maintenance. Table 11 provides an outline of different options for irrigation of green roofs.

Automatic systems

If an automatic irrigation system is to be installed on a green roof, consider a system that incorporates a rain sensor that shuts off the system in the event of rainfall above a certain threshold. This removes the risk that the roof loading may be compromised if the irrigation system is running during a heavy downpour. Even automatic systems require regular physical checks and operation tests.

Low irrigation

It is important to understand that, while some succulent species can survive on rainfall alone, plants that experience moisture stress will decline over time. This leads to a loss of vigour, leaf shedding, canopy reductions and ultimately plant death. Plant failure means more water run-off from the roof, less transpirational cooling and more opportunities for weed invasion. As such, irrigation is advisable. However, if designing for very low water use, select plant species that are better able to tolerate the extreme moisture stress on a green roof during a typical summer. Selection tools to guide the identification of low water use plant species can be found at the *Smart Garden Watering* website. Another option is to provide supplementary irrigation on a contingent basis during the hotter periods of the year.

Depending on the level of attention that can be provided, inclusion of indicator species with moderate requirements for water may be helpful to show when supplementary irrigation is necessary. This avoids compromising the performance of all the plants.

Irrigation frequency

During the establishment phase after planting, irrigation may be frequent, for example, two to three times per week. For food crops, irrigation will also be necessary during high activity phases of the growth cycle, such as when the plant moves into flowering and fruit set. The frequency of irrigation should be matched to the drainage and water-holding capacity of the mix: frequent irrigation of a very free-draining substrate is likely to waste water.

The irrigation delivery method will partly determine the timing of irrigation. Watering in high daytime temperatures will transfer more heat into the building, as water heats up as it passes through the hot growing substrate and transfers some of this heat into the building when it drains onto the roof surface. For surface and sub-surface irrigation, there is little to no wetting of the foliage, which lowers the risk of fungal disease. If spray irrigation is used, it should be applied very early in the morning to enable foliage to dry off throughout the day and thus reduce the likelihood of disease.

Moisture sensors

Be aware that moisture sensors used to estimate moisture content in standard landscaping soils do not provide reliable information about the moisture content of free-draining, porous growing substrates used on green roofs.

An irrigation system is laid at the Victorian Desalination Project green roof, Wonthaggi. Image: ASPECT Studios

Table 11. Irrigation methods for green roofs

Delivery method	Advantages	Disadvantages
Microspray	Low cost, visible, easy to install, reliable	Uneven distribution (plant interception), high water loss (wind, evaporation), foliage wetting (increased disease potential)
Surface drippers/ perforated pipes	Low cost, visible, even delivery of water	Moderate water loss
Sub-surface drippers/ perforated pipes	Low cost, moderate efficiency (water delivery to root zone)	Non visible (difficult for maintenance), higher potential for damage by people digging
Sub-surface capillary	High efficiency	High cost, maintenance and repair is difficult because not visible, 'capillary rise' of substrate needed or water will not reach plants
Wicking associated with irrigation in drainage layer	High efficiency, ease of installation	Linked to proprietary systems, 'capillary rise' of substrate needed, this may be unsuitable for plant establishment if the water is applied too deep for the plant roots to reach
Hose	Good for domestic application for easily accessed areas, not so good for other areas. Allows monitoring to occur at the same time	Cost (requires someone to be present on site), low water efficiency, foliage wetting, uneven distribution

5.11 Wind considerations

Even on flat roofs, wind uplift may present serious challenges for retention of substrate and plants. Wind damage can be dangerous to people and property and costly to repair. Retention systems may be required to ensure that materials cannot be blown off the roof.

Wind uplift pressure is lowest on the centre of the roof and highest at the edges, around the perimeter and at corners. The higher the building, the greater is the risk. On pitched roofs, the roof peak is also subject to uplift. Minimising untethered components greatly reduces the risk of damage to the green roof by uplift.

Where possible, waterproofing should be fully adhered to the roof, or mechanically fixed. For waterproofing layers that are not bonded to the roof, the green roof assembly must provide adequate ballast to prevent uplift. Edge treatments are the most critical: the un-vegetated zone around the perimeter of a green roof (see Chapter 5.13) may require heavy concrete paving slabs rather than loose gravel ballast. The materials used must conform to the design wind load calculated for the specific green roof location.

On some green roofs, perimeter balustrades or parapet walls will provide some protection against wind flow. Other treatments, such as jute erosion control netting (see Chapter 5.12) or coated wire retaining systems, may be useful.

Plant selection may also be used to mitigate the impact of winds. If the tolerance of different species to wind exposure is understood, plantings can be planned so that the lowest-growing, most robust species are planted in the most exposed areas. Taller, less wind tolerant species are installed behind them. The resulting gentle gradation of vegetation heights interrupts, and slows, wind flow over the planting.

Perforated screens reduce wind flows on The University of Melbourne's demonstration green roof at Burnley campus

Fytogreen design uses wind tolerant species to shield others on the green wall at the Triptych Apartments, Southbank

5.12 Slopes and wind protection

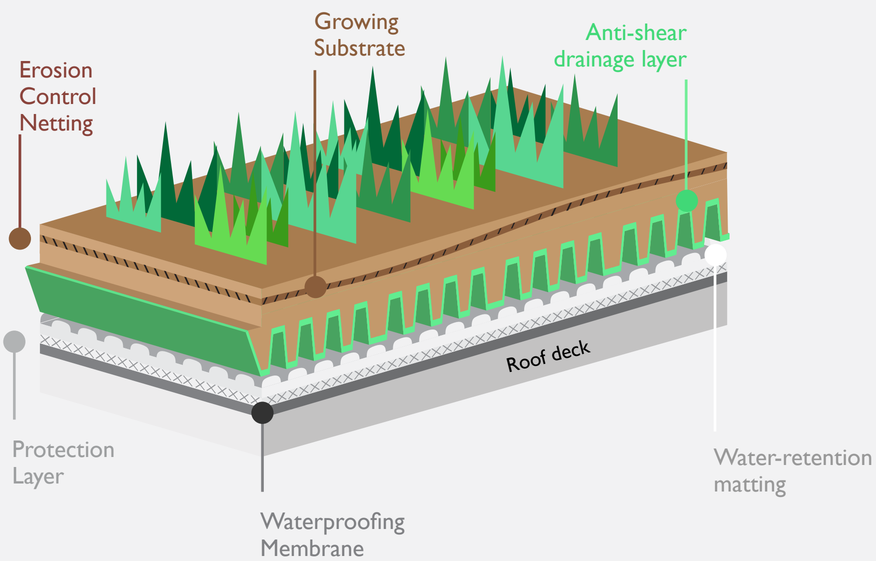
Landscapes on pitched roofs are subject to wind forces and gravity affecting the stability and retention of the growing substrate and plants. In many cases slippage can lead to poor plant performance and ultimately green roof failure. For roof pitches of up to 15 degrees, no additional protection is needed, unless there are strong wind issues on the site. Waterproofing must be root-resistant, and covered with a protection mat. A drainage layer is not always required as the roof can drain effectively through gravity. The stability of steeply pitched green roofs is increased by maintaining vegetation cover: provision of irrigation is essential.

For green roofs constructed on pitches greater than 15 degrees, basic protection can be provided through anti-erosion jute netting installed just below the substrate surface to provide some anchorage to plants (see image). This netting breaks down over time, and is used simply to help keep the substrate in place whilst the plants establish.

Greater protection can be provided on steeper sites by using a drainage layer with large cells, or cups. The growing substrate fills the cells of the drainage layer, reducing slippage and providing spaces for plant roots to grow, ensuring further stabilisation (see Figure 20). A filter sheet must be placed beneath the drainage layer to reduce wash-through of fine particles from the substrate.

For green roofs with slopes between 20 degrees and 45 degrees, 'honeycomb' webbing, comprising multiple, enlarged drainage cells, can be installed above the drainage and filter sheet layers (see image). This holds the substrate in place, increases stability and reduces slippage. Other specialised structural elements can be incorporated to transfer shear forces into stable, reinforced abutments that form part of the roof structure, or wind barriers can be installed.

Figure 20. Layers of a sloped roof



A green roof on a slope can include a drainage layer with large cells to retain substrate as well as a layer of erosion control netting laid close to the top of the substrate to help retain substrate and plants during the establishment period

Anti-erosion jute netting installed on a sloped green roof. Ideally a layer of substrate should be covering the netting, which will degrade over time. Image: PAD Creations

Honeycomb webbing used to stabilise substrate on a pitched green roof. Image: KHD Landscape Engineering Solutions

5.13 Hard landscape elements

Some of the functional elements that are used in green roofs include:

- non-vegetated zones
- retaining edges
- topographical construction
- planting containers
- drains and gutters
- flashings
- a range of other elements, not discussed in detail here, such as: harness attachment points; controller boxes/solenoid boxes (to house irrigation components); decorative and functional landscape elements such as decking, paving, seating, shade protection, ponds and lighting

The colour of materials should be considered as this will affect their heat gain. Consider location of shade structures as additional elements.

Non-vegetated zones

Non-vegetated zones are used to group roof penetrations, vent pipes and other upstands and assist in lateral drainage. They are generally constructed with large diameter aggregate rock or ballast (16-32 mm size), rather than the growing substrate, and provide additional lateral drainage into the roof drains. They are usually between 300-500 mm wide and are separated from the roof perimeter ballast by metal edging installed around the planting area. Similar vegetation-free zones may be created through use of paving slabs or ballast to provide access pathways across the green roof, or as firebreaks on very large roofs.

Retaining edges

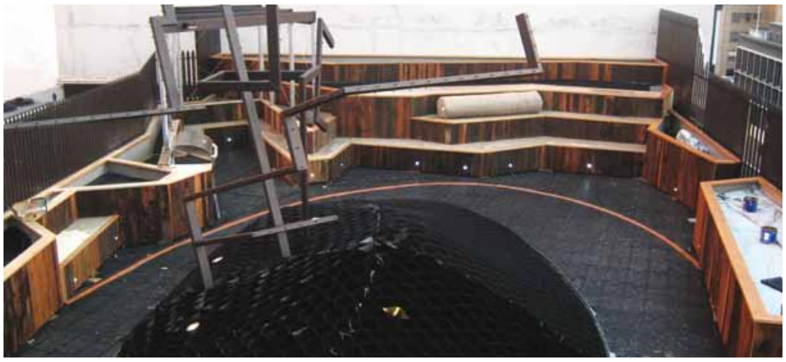
Edging can be used to define and retain planted and non-vegetated zones across a green roof. It can include concrete, stainless steel, recycled plastic or aluminium products; L-shaped edges are installed above the filter sheet and often have perforations to allow drainage through the profile.

Edging can be used to separate different substrates on the roof

Topographical construction

Blocks of polystyrene foam can be used to build up areas to create mounds or hills without the additional weight of the substrate. Topographical variations on a green roof create different growing conditions and microclimates to increase habitat opportunities for beneficial insects, as well as visual, aesthetic interest.

Non-vegetated zone around hard infrastructure on a roof



The build up of this green roof 'hill' in Queen Street, Melbourne, is created from recycled expanded polystyrene blocks, overlaid with a deep drainage layer to contain the growing substrate

Planting containers

Planters must be made from weather resistant materials, and the components must be physically and chemically compatible with each other. Common examples of materials used to build planting containers are powder-coated metal, galvanised steel, ceramic, timber, UV stable plastic and glad reinforced concrete (lightweight concrete).

UV stable plastic containers are used to add greenery to this rooftop garden in Little Collins Street, Melbourne

Drains and gutters

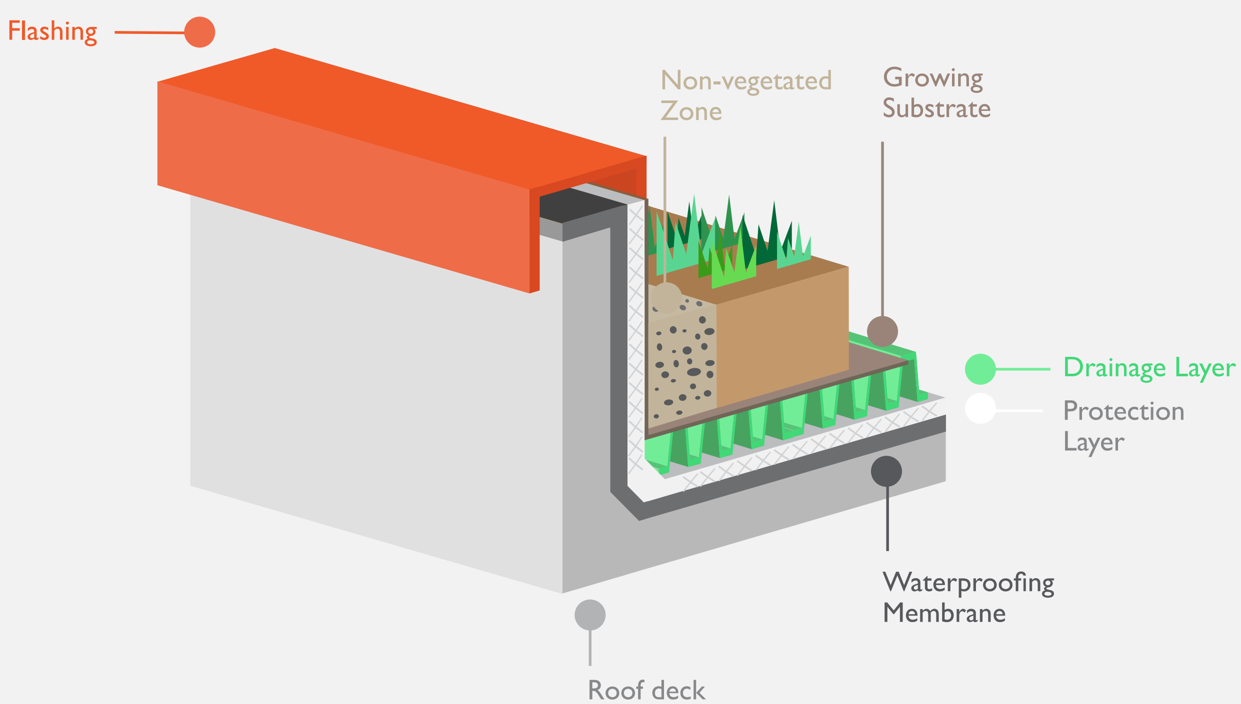
All drains must be accessible for maintenance, protected from blockage by leaf litter and substrate wash, and housed with inspection chambers, drain covers, filters or strainers. Inspections after construction, following storms and every three months are recommended.

Selection of drainage hardware depends on the required function and appearance; examples are provided in the section on drainage in Chapter 2. For drains located flush with the roof surface, a grille should be installed to prevent drain clogging.

Flashings

Roofs with a parapet that extends above the roof deck require installation of a cover (flashing) to protect the building fabric. This should be included in the waterproofing installation to ensure that membrane terminations, and any areas of membrane extending over the vertical and horizontal surfaces of the parapet, are not exposed.

Figure 21. Functional elements on a green roof can include flashing (capping) and non-vegetated zones



Stages of construction: Building the City of Monash green roof

1 *The roof deck is ready for installation of the green roof: waterproofing treatment was not required on this clip-lock steel roof* **2** *A protection layer is used to cover the roof deck* **3** *Drainage sheets are installed over the protection layer* **4** *Abutting drainage sheets provide full coverage of the area to be planted* **5** *Substrate is pumped up to the roof from ground level and installed via a blow hose.* **6** *Edging strips are used to separate planting areas from non-vegetated walkways* **7** *Planting follows a specified design* **8** *The final product*

Images courtesy of PAD Creations and Junglefy

External green walls, Illura Apartments, Roden Street, West Melbourne

6. BUILDING & INSTALLATION

GREEN WALLS

Green wall systems vary greatly in their design and construction from DIY projects to modular green wall systems available to buy 'off the shelf', through to proprietary systems that are custom-fitted to a wall. Specialists in green wall design and installation can provide advice on the most suitable system and the best construction approach. Green walls can deliver more than aesthetic benefits, and this requires consideration in the design stage. This chapter provides advice on the structures and components required for green wall systems, waterproofing, irrigation and nutrition, vegetation and lighting. This information should be read prior to starting a green wall-building project.

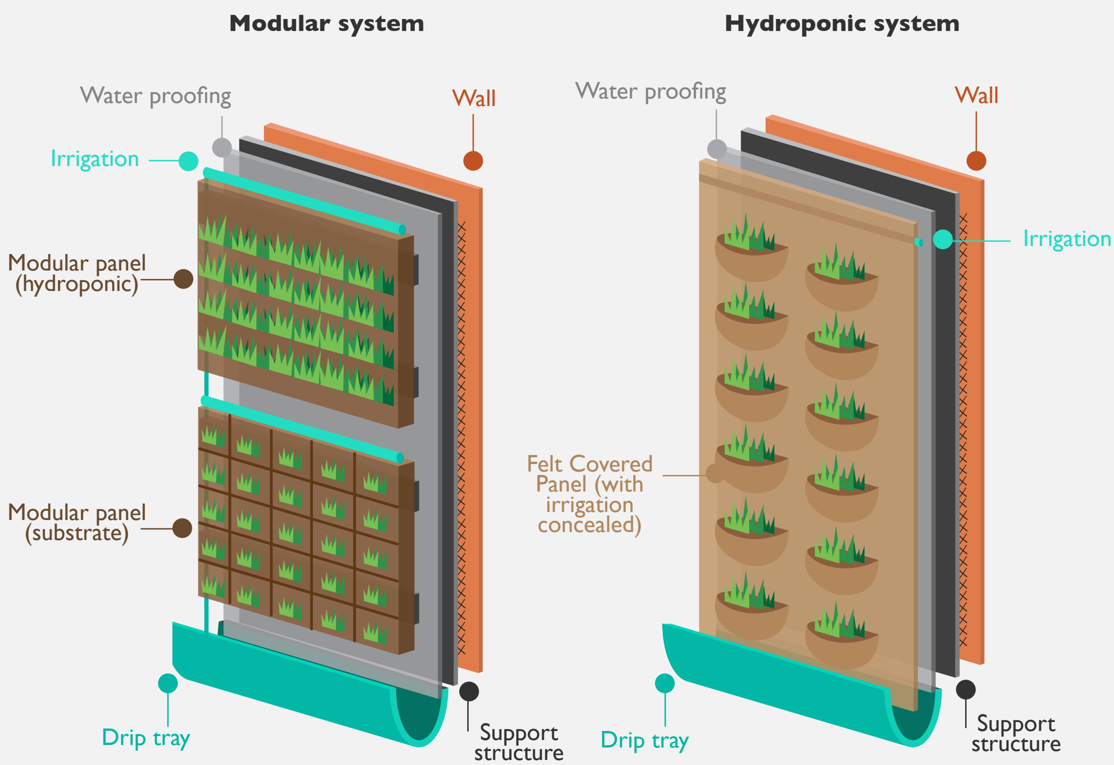
6.1 Structures and components for green wall systems

Hydroponic green wall systems can be either modular containers or large panels. The systems are installed via brackets that sit out from the load-bearing wall (or a stand-alone structure) to create an air gap between the wall (or other structure) and the backing sheet of the green wall system. In a hydroponic system, an inert growing medium is provided to which the plants physically anchor, such as a horticultural foam, a mineral fibre or a felt mat. These materials can act as a water retentive sponge, although the more they soak up the heavier the system becomes. The advantage of the hydroponic system is that there is no structural decay of the growing medium, no salt build up from fertilisers and nutrients are supplied in a precise and controlled manner. Over time, plant roots grow and ramify through the entire system to create a very robust network.

Substrate-based systems use substrate-holding containers made of plastic or metal. The substrate is packed directly into the empty container or placed in a water permeable, synthetic fibre bag. The containers are connected together and anchored to the wall or to an independent, structurally secure metal rack or framework. Alternatively, plastic or metal growing containers can be hung on a metal grid fixed to the wall. Individual growing containers can be removed for maintenance or replanting. Most substrate-based systems are designed for automatic irrigation, just like the hydroponic green wall systems.

The growing medium in these systems provides a structure to support the plant and facilitates water, air and nutrient access, decreasing the need for constant management associated with hydroponic systems. However, over time the reserve of nutrients will be exhausted and there can be a build up of salts in the growing medium. Traditional potting mix is not a suitable substrate for green walls. A specialist green wall provider will advise on the most appropriate growing medium for a particular green wall design. See also Appendix A for information about substrate characteristics.

Figure 22. Types of green wall configurations



Green wall systems vary enormously, these are two general types. - modular, which can be hydroponic or substrate based, and felt covered hydroponic panels. Note that the support structure and waterproofing are optional and depend on the site

Drip trays are used to capture excess irrigation water from the growing medium as well as water droplets that drip off foliage. The size of the drip tray should be sufficient to hold an entire irrigation cycle's water volume (before draining away prior to subsequent cycles starting). Drip trays may not be necessary if the run-off is intended to irrigate vegetation below the green wall. If drip trays are not used, ensure run-off does not create slip hazards, damage the building fabric or provide excess moisture or nutrients to ground-based plantings below.

Water captured in the drip tray or reservoir at the base of the planting system can be pumped back to the top of the wall for re-use rather than being wasted, provided that it is treated to prevent build-up of nutrients. Drip trays should have a drainage pipe of sufficient diameter to empty the drip tray or manage water capture sufficiently to mitigate overflow of the tray. Fascia treatments may be added to conceal the edges and functional elements of the green wall system, such as the irrigation system and drip tray.

6.2 Waterproofing

Waterproofing is project-dependent; in some cases there will be a sufficient air gap between the back of the planting system and the wall, making waterproofing treatment unnecessary. The air gap prevents movement of water between the wall and the planting system, and air-prunes plant roots to reduce the risk that they will directly contact the wall and provide a path for movement of moisture. Provision for an air gap between the planting system and the building wall will also prevent growth of mould. Where waterproofing is necessary, it will prevent damage to the wall from moisture and dissolved salts from fertilisers. In some cases the supporting wall might be considered waterproof as is; for example, a preformed concrete wall may be thick enough to be rated as fully waterproof, or a wall constructed from marine-grade plywood will have some degree of waterproofing from the glues used within the ply. Consideration must be given to waterproofing penetrations to the wall as well as junctions between surrounding fascia (if used) and junctions between wall waterproofing and drip trays (see box). Roller-applied liquid waterproofing treatments can be used on internal and external green walls. When considering waterproofing for any green wall, seek advice from a waterproofing consultant to ensure the most suitable treatment is chosen.

The manufacturing and installation of waterproofing membranes should comply with the Australian Standard for membranes used to waterproof exterior areas of buildings (AS 4654.2-2012 Waterproofing membranes for external above ground use – Design and installation). Waterproofing membranes used for internal walls should be manufactured and tested to AS/NZS 4858:2004 Wet area membranes. Waterproofing treatment should follow the procedures used in other internal areas of residential buildings, such as bathrooms, kitchens and laundries. These are specified in AS 3740-2010 Waterproofing of domestic wet areas.

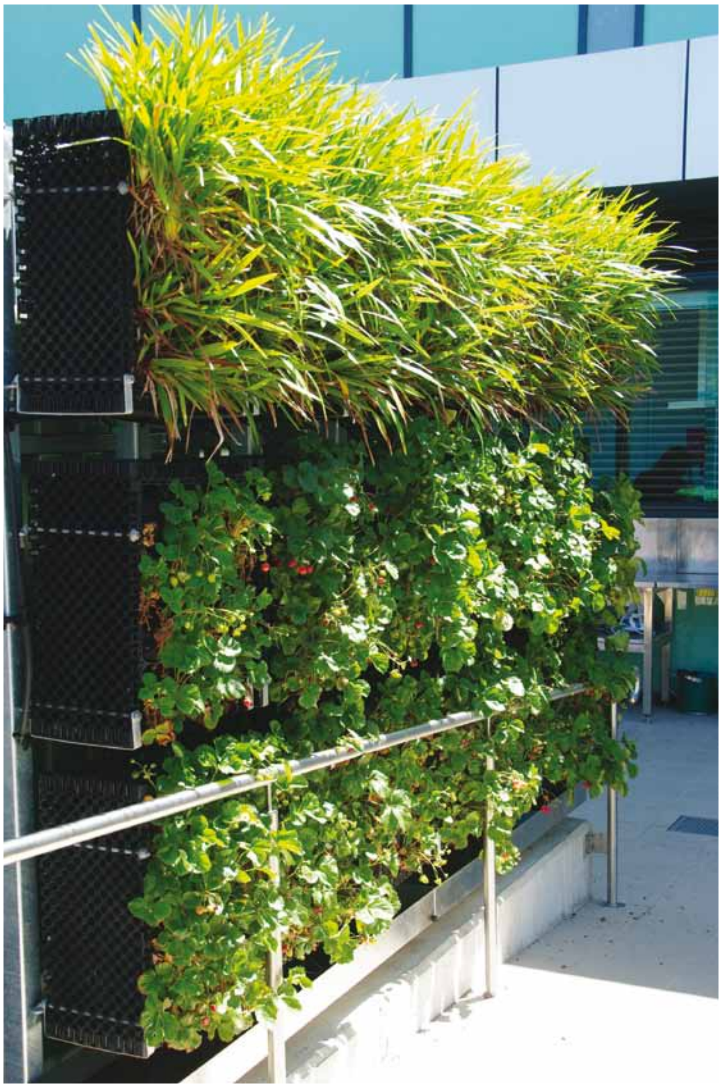
Waterproofing walls - lessons learned

This indoor green wall is located within an office conference room in Melbourne. Within a week of installing the waterproofing and drip tray treatments, water leakage was observed. The area connecting the waterproofed wall to the drip tray had not been completely sealed and allowed water to collect and drain between the two.

The modular nature of the green wall assembly enabled this fault to be easily repaired the area was sealed, and this mitigated any further damage.

This example reinforces the importance of testing and checking the work undertaken and completed by every contractor against project specifications.

An improperly sealed join created a leak behind this green wall



This green wall on the roof of a health care centre in Marion, South Australia, incorporates an inbuilt water tank to provide water supply and structural integrity for double sided modular wall systems, with plantings including strawberries and herbs. Image: Fifth Creek Studio

6.3 Irrigation and plant nutrition

Green walls cannot be sustained without irrigation. Interruptions to the water supply are a common cause of plant failure on green walls. Systems designed with inbuilt irrigation should mitigate plant losses due to inconsistent moisture management, although errors can still occur.

Automated, remotely controllable irrigation systems are used for walls in high profile locations, or in situations where access is challenging. Note that the quality, design and costs will vary between different systems. The most sophisticated systems enable the maintenance supervisor to keep track of the automated performance of the system, including the volume of irrigation delivered, its frequency, substrate moisture content, as well as pH and nutrient levels in the water supply. The settings can be overridden if needed; for instance, the frequency or duration of irrigation cycles may be increased on hot days.

In hydroponic systems, plant nutrition is delivered by a fertiliser injection system that releases controlled doses of fertiliser into the irrigation system (fertigation). Management of fertigation systems and rates of delivery requires specialist knowledge, as it is more complex than fertilising soil or growing media. Hydroponic systems require continual monitoring of pH, water hardness and total dissolved solids (TDS), and adjustment of these parameters where necessary.

For hydroponic green wall systems, the fertigation system may apply 0.5-20 litres of irrigation solution per square metre per day. Internal green wall requirements are at the lower end of this range, and external green walls at the higher end. Irrigation cycles typically last a few minutes and will be required several times a day. Keeping irrigation volumes low minimises waste and reduces run-off. Irrigation run-off may be captured in a tank at the base of the wall and recycled back through the green wall system.

Green walls that use a high quality, water-retentive growing medium, and are not in an exposed or particularly hot location, may thrive on a weekly watering regime. In most simple, soil-based systems, including DIY systems, controlled release fertiliser is mixed in with the growing medium, rather than using a fertigation system.

Irrigation must be available as soon as the plants are installed in the wall system. The irrigation system requires a water meter to monitor irrigation volume, and a pressure gauge to monitor the even application of water. The need for ongoing regular irrigation and the expectation that water will be used sustainably means that stored (harvested or recycled) water should be used whenever possible, so a pump is necessary.

6.4 Vegetation

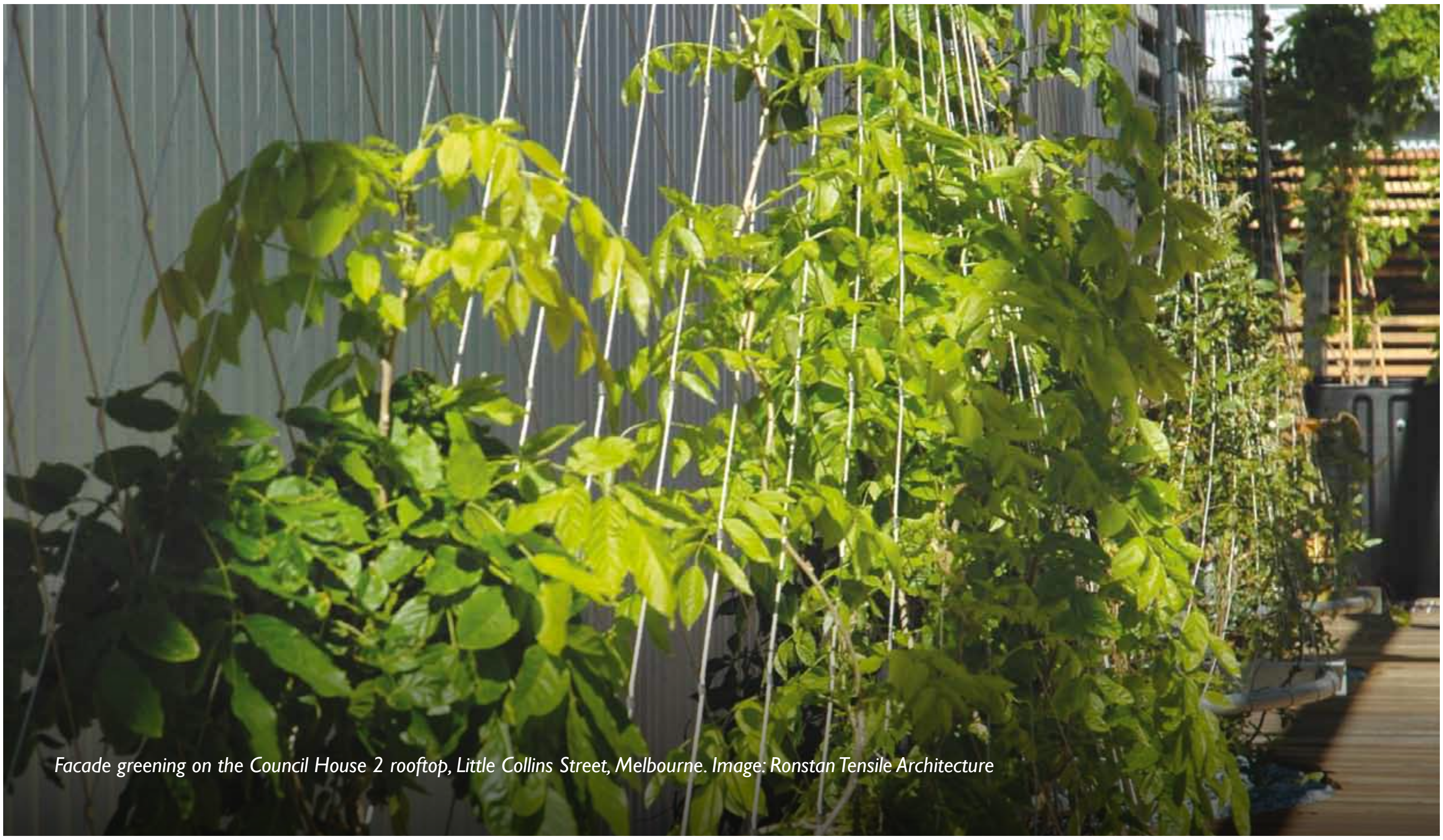
The size of plant materials used in green walls will depend on the required look and finish of the wall at project completion. Planting densities can be as high as 25 to 30 plants per square metre. Decorative patterns can be designed by repeat planting across an area; however, these patterns can be difficult to implement if shadows and light across the different parts of the wall have not been considered. Systems incorporating smaller plants at the outset will take longer to fill out than those using well-established container plants. The dimensions of the planting module will determine the size of the planting stock. Different green wall systems will be better for different types of plant growth habits, from those that grow upright to those with a clumping growth habit, scrambling, cascading or creeping. See Chapter 3 for information on plant selection.

6.5 Special considerations for walls

Lighting is often required for green walls positioned in low light exposure areas. Many green walls are installed within non-lit areas. Lighting green walls is highly specialised, requiring the services of a lighting designer or engineer. Plants require very specific lighting quantities and qualities to photosynthesise, grow, flower and develop appropriately. Tropical and subtropical green wall installations can generally survive in lower light conditions than Mediterranean, temperate plantings. Extensive knowledge of horticulture and design of green wall systems is needed to choose the right species for the light levels available on-site.

Another consideration for green wall installations is air movement around the foliage. This is important to help prevent fungal growth, and additional ventilation may be needed to ensure sufficient air movement for indoor walls. Outdoor walls usually create their own microclimate that creates enough air movement, but in very sheltered positions attention should be given to this issue.

Internal green wall. Image: KHD Landscape Engineering


Facade greening on the Council House 2 rooftop, Little Collins Street, Melbourne. Image: Ronstan Tensile Architecture

7. BUILDING & INSTALLATION

GREEN FACADES

Green facades can range from complex systems for multi-storey buildings, with plants growing in containers at different heights, to simpler systems where the plants grow from the ground, allowing inexpensive installation of greenery on low-rise buildings. This chapter provides information about building and installing green facades. The information should be considered prior to starting a building project.

7.1 Wall protection and different facade treatments

Waterproofing treatment of the wall is not required for green facades. It is important to select plant species with a growth habit that will not damage the fabric of the wall. Some species with adventitious roots or scrambling stems can damage the building fabric over time, such as Common Ivy *(Hedera helix)*. However, self-clinging climbers are exceptionally well suited to many vertical building surfaces, particularly old stone structures or those with minimal exposed mortar, and have lasted a long time without negative impacts on the building fabric.

Plants can damage buildings by physical and chemical means, over timescales of centuries. Damage can be superficial, causing only aesthetic changes to the facade, or more structural damage may result, usually over much longer time periods. If in doubt, choose a green facade where the plants are grown on a support system that is installed separately from the building.

Support systems for facades involving plants that have tendrils or twining stems (see Chapter 3) may be made of plastic, timber, metal, or stainless steel cables or cable mesh. Design of the support system must consider the intended lifespan of the facade, the growth habit of the plant species, and how spacing and offset from the wall can help to provide the desired end result. Possible designs are shown in Figure 23.

For containerised systems, plant species choice and the spacing and volume of containers are critical for establishing effective facade coverage. Specialists in green facade design and installation can provide advice on the most suitable system and the best construction approach.

Wooden trellises are prone to damage by weather and plant growth and many plastics become brittle over time with ongoing exposure to UV light, heat and cold.

Metal systems have the longest lifespan and require less maintenance. Stainless steel cables and trellis are low maintenance and have a long lifespan and probably offer the greatest flexibility to suit a variety of plant species and wind loads. Steel nets and mesh provide additional options, with closer 'weaves' than horizontal and vertical cabling.

Support systems are suitable for very structured arrangements where greening has to be maintained away from windows or because of the other building constraints, such as the geometry of the building facade. A facade support may provide aesthetic appeal when the plants have not yet grown to full size and in winter where deciduous climbing species are used. Support systems can be separate from a building and used to create a green facade for privacy or shade.

Figure 23. Support structures for green facades grown with twining climbers

Single cables provide subtle screening and prevent people climbing

Stand-alone trellis systems provide intrinsic visual interest

Containerised mesh system for multilevel structures

Wall-mounted cable grids can cover plain unsightly walls

7.2 Soils and growing substrates

Plants used for facade greening may be grown in soil in the ground, or in containers filled with a well-designed growing medium. The principles outlined in growing substrates for green roofs, outlined in Chapter 5 and Appendix A are also relevant to green facades.

The use of planter boxes, mounted at varying heights above the ground, can allow greater coverage of the facade, where the building is so tall that ground level plants will not reach the top. The advantage of in-ground planting, where soil is of a reasonable quality, is that the plants will have more access to water (the soil will not dry out as quickly as in a container) and will have more space for their root systems to grow.

Container growing media must be designed to support ongoing growth of plant shoots from a limited, contained root volume, and at elevation. Although many climbing plant species have superficial root systems and may thrive in a small volume of substrate, there is a notable link between root volume and sustainable foliage volumes. Climbers required to cover greater areas will require greater substrate volumes. However, weight loading restrictions may limit the depth that can be supported for container systems at elevation.

In-ground plantings will generally outperform container plantings in the long term. Ensure the planting bed soil or growing media has a suitable balance of porosity and water-holding capacity, and an adequate supply of nutrients to ensure optimal growing conditions. In a garden setting with good quality soil and adequate irrigation, there should be little to impede strong plant growth. In city landscapes, with large areas of impervious paved surfaces and soils that may be highly compacted, soil structure may be poor. In such cases, consider installing a 'structural soil' that can be compacted to enable footpaths or other hard surfaces to be installed, while still providing adequate porosity to support root growth. In some buildings the foundations sit out from the wall, underneath the ground – these footings should be set deep if a garden bed is planned adjacent to the wall.

Seek the advice of a horticultural consultant to ensure the volume of soil or growing medium will support the desired height and spread for the green facade.

7.3 Vegetation

For rapid coverage of a green facade, plant specimens should be healthy and vigorous, with numerous basal shoots. They should be of the largest possible size to suit the installation.

To support the vegetation at installation, the growing substrate used to support container-grown facade plantings should incorporate controlled-release fertiliser at planting (see more information about plant nutrition in Chapter 8). New plantings should receive irrigation to promote their strong establishment, which depends on season planted and plant size. Establishment is when new roots have grown and the plant is acclimatised and actively growing.

Pruning and training of new plants is essential to promote the development of an effective facade. Plants may need to be trained to the facade support, or temporarily attached to the wall after planting, to encourage upward growth. Once the plant is established, the main runners should be trimmed to encourage lateral shoots that will create a more radial growth pattern. If this is not done, the climbers will typically branch out only once they have reached a significant height, and it may take years for the lower portions of the facade to receive any coverage. The use of diagonally oriented cables on facade systems facilitates horizontal, as well as vertical, growth of the plant (preferred over the plant shooting straight up) and thereby increases the density of foliage cover. For long-term installations, pruning to rejuvenate might be required. As climbers age their growth can decrease and cutting back to hard wood can revitalise a plant and allow for longer lifespans. This means that after five to seven years, especially with woody climbers, it may be necessary to prune back a large portion of foliage.

Close-up view of adherent discs that enable species such as Parthenocissus tricuspidata (Boston Ivy) to self-attach to this building facade at RMIT University, Melbourne

7.4 Drainage and irrigation

Garden beds, or at-ground planter boxes used for climbing plants for facade greening, should have drainage appropriate for the plant species selected for use. Container systems placed at elevation on the face of a building should have a free-draining growing substrate to avoid potential waterlogging in the event of prolonged periods of wet weather. The potential for ponding of water above the top of the growing substrate should be minimised by providing overflow drainage holes in the sides of the container, just higher than the level to which the container is filled. In most cases, run-off through the base of the growing containers will simply run down onto the ground beneath, but drip trays can be installed to collect water.

The vigour of many climbing plant species means that irrigation will be required to maintain high-density foliage cover and long-term performance of the green facade. In-ground plantings in domestic settings will need irrigation at least during the hotter months, if not year-round. Harvested, recycled water should be used for irrigation wherever possible. Irrigation frequency will depend on the plant species selected, the type of growing medium used, and how exposed the facade is to sun and drying winds.

At-ground plantings can be irrigated by automatic systems or manually with a hose. Surface or sub-surface dripper systems are suitable automatic systems. Irrigation supplied to elevated planters requires appropriate water supply pressure from tank, recycled and mains water supplies. See Chapter 5.10 for information about irrigation systems and methods of delivery and Chapter 3 for more information on drainage and irrigation in general.

Facades in containers — lessons learned

A roof garden incorporating green facades was built at Council House 2, central Melbourne, in 2006. Its design included the incorporation of 950 mm deep plastic planters, connected to a cable and stainless steel trellis (X-TEND®) mesh for growth of the facade. The intention was to increase greenery across the building through use of the roof and facades.

Unfortunately, the facade plantings have not grown well due to multiple problems with the planters, growing substrate and irrigation. The black colour of the planters leads to considerable heat gain in the root zone over summer, causing difficulties for plant growth. The planters also tend to split, the side wall plastic seemingly unable to tolerate the high bulk density of the growing substrate. Additional metal frames were used to support the replacement containers. The substrate itself has also had issues, with plants failing or growing poorly and a considerable drop in the total volume since installation. A further complication has been the irrigation system. Each planter is irrigated via combination of a valve, water reservoir and foam 'wicking', all enclosed in the base of the container. The valves function at a much lower pressure than the mains supply, meaning most failed when they were first operated. This in turn affected any possible 'capillary irrigation' upwards to the root zone in each container, leading to extensive plant death shortly after installation. Replanting has occurred but all containers now need to be hand-watered. The City of Melbourne is currently investigating cost effective options for resolving these problems.

The City of Melbourne recommends thorough research or peer review to assist and support decision-making around the design and use of new technologies.

Planter boxes on the City of Melbourne's Council House 2 roof garden, Little Collins Street, Melbourne, have not performed as well as expected


Weeding the vegetable bed on the Demonstration Green Roof at The University of Melbourne's Burnley campus

8. MAINTENANCE

This chapter provides information to help with the development of maintenance plans. A detailed maintenance plan will outline performance standards, tasks to be undertaken and the resources required to achieve them. Once created, maintenance plans should be reviewed at least annually to ensure all maintenance needs are being met.

8.1 Maintenance planning

A maintenance plan should include a clear description of:

- maintenance objectives – created based on the design intent, or the landscaping or environmental objectives that were the basis for the roof, wall or facade development
- performance targets, such as the time frame for complete coverage of an area by plants and foliage
- responsibilities of various personnel involved in operating the building, outlining the type, scope, duration of task and occurrence
- training requirements (such as Working at Heights certification) and safety equipment
- resources available

Maintenance planning should also incorporate risk management, with the aim of reducing or eliminating the likelihood of failure that could result in property damage or personal injury.

For large projects, maintenance planning is often based on 'asset management planning' where the whole life of the asset is considered, including design, construction, establishment, operation, maintenance, renewal and demolition/replacement.

For some green roofs, walls or facades, particularly those located on commercial premises, maintenance will be undertaken by someone other than the building owner. A maintenance agreement with the installation company or with a recommended third party may be the most economical way to ensure the best long-term performance of a green roof, wall or facade. If a maintenance contract is used, it is important to be clear about the duration of the maintenance agreement, the scope of maintenance responsibility, and the need for handover at changeover to either new contractors or back to the building owner.

A supervisor may be designated to oversee the overall and ongoing management of maintenance activities, and can provide direction to maintenance staff and assess that work has been carried out satisfactorily. The supervisor's role will involve:

- scheduling of maintenance: flexibility may be needed, as, for instance, additional visits may be necessary to repair damage following extreme weather events
- signing maintenance contractors in and out at the start and end of a visit, offering a toolbox talk at the commencement of a visit, and providing keys and providing any specialist equipment that is required
- occupational health and safety: ensuring contractors have appropriate certification; scheduling mandatory annual checks (and repair or replacement if necessary of safety anchor points); ensuring conditions are safe for maintenance staff to perform their work; providing safety signage or other barriers to restrict access during maintenance; and ensuring that staff understand the process for reporting actual or potential hazards
- informing other contractors who work on the building about the roof, wall or facade, so that they do not inadvertently damage the asset (for example, water service contractors turning off water for a prolonged period)

Reactive maintenance was needed after a severe hail storm shredded succulent vegetation at The Venny, Kensington, in March 2010. Image: PAD Creations

8.2 Maintenance tasks

Maintenance falls into a number of categories:

1. **Establishment maintenance** occurs during the first one to two years after installation and is undertaken to fully realise the design intent and outcomes. For vegetation, this includes tasks such as pruning, weed control, and irrigation to ensure healthy and vigorous plant growth.
2. **Routine or recurrent maintenance** includes regular works that are undertaken to ensure the roof, wall or facade is maintained to a minimum or required standard of appearance, functionality and safety. For vegetation, this can include tasks such as weeding, pruning, removal of leaf litter and, in some cases, mowing.
3. **Cyclic maintenance** is scheduled interventions at less frequent intervals that maintain infrastructure. It includes maintenance of the underlying building structure and of specific components of the green roof, wall or facade system. This may include infrequent pruning or other formative management of woody vegetation, such as coppicing, or annual treatment of decking or other hard landscape elements to maintain their safety and functionality.
4. **Reactive and preventative maintenance** is undertaken when some component of the system fails suddenly, or shows signs of imminent failure. Failure may be due to a long-term problem that has gone undetected (such as blocked drains by tree roots), or sudden damage resulting from an extreme weather event (such as stormwater incursion).
5. **Renovation maintenance** includes works that change the design intent. This may arise after a change of ownership of a building which instigates a desire for change, through to remediation of a design failure (see The Venny case study).

Some typical maintenance activities for green roofs, walls and facades are outlined in the table below. These are intended as a general guide only: each site will have its own specific requirements and some listed will be more relevant and/or specific to a wall, roof or a facade.

Access for maintenance

Roofs that are not generally accessible to the building owner or tenants may need to be accessed by ladder, using ropes and harnesses or other 'fall arrest' systems to work safely. For small wall and facade installations, within a few metres of the ground, a mobile work platform at ground level is probably the most efficient solution for access. However, ropes and roof-mounted attachments may be required for larger areas or higher buildings. Green walls and facades extending more than 10 metres above ground level will usually be maintained from a roof-mounted work platform. A hybrid living wall system developed in Adelaide addressed maintenance access with an inbuilt platform at each floor level that allowed safe access for maintenance of the vegetation and for other services such as window cleaning.

At The University of Melbourne's Burnley Campus, vigorous deciduous climbers such as Boston Ivy (Parthenocissus tricuspidata) are pruned twice a year to control size and to keep stems away from windows, flashings, drains and other building fixtures

Table 12. Common maintenance tasks

Maintenance Objective	Task
Maintain planting design	Plant replacement, infill plantings
Maintain plant growth	Remove waste plant material (leaf litter, prunings, weeds), inspect for signs of pests or disease and treat as needed, make seasonal adjustments to irrigation volume and frequency as needed, ensure adequate nutrition levels for plants; inspect after severe weather events (e.g. wind or heat) to look for signs of stress
Minimise weeds	Mulching, weed control
Manage lawns	Regular mowing, annual renovation
Maintain trees	Regular pruning, annual tree inspection, brace and support as needed
Maintain climbing plants	Annual or biannual pruning to maintain density and cover and to remove growth from fixtures (windows, drains). Rejuvenate to renovate habit and growth
Rejuvenate climbing plants	Vigorous pruning to renew stems and encourage new basal growth (every 5-7 years)
Monitor plant performance	Maintain records of plant health, vigour and coverage, pest and disease impact
Maintain substrate	Top-up of growing substrate may be required due to wind, rain or animal activity (check the depth of the growing substrate before any additions are made to ensure weight loadings are not exceeded)
Maintain irrigation (and fertigation) systems	Manually test and inspect the irrigation system regularly and monitor any automated systems (check volume of irrigation delivered, its frequency, substrate moisture content, and, for hydroponic green walls, nutrient levels in the water supply)
Monitor plant nutrition	Maintain a log of fertiliser additions and records of pH and electrical conductivity values before and after addition of fertiliser
Maintain drainage	Ensure roof drains are clear and functioning, remove dirt, litter and other deposits from drain inspection chambers, check plumbing hardware, check condition of filter sheet and deeper layers if necessary
Maintain non-vegetated zones	Remove vegetation from perimeter zones and around other equipment and fixtures
Maintain wind protection features	Check the condition and fit of protection systems
Maintain safety systems	Check safety anchor points for fall arrest systems, check access points, e.g. ladders and stairways, check electrical safety of power points, lighting and irrigation control system
Maintain waterproofing	Inspect flashings over waterproofing membrane terminations, inspect wall fabric for any damage from water, fertiliser or plants, conduct leak detection of waterproofing on a green roof – if possible
Maintain other hardscapes	Clean or oil decking or furniture, inspect green wall or facade support systems for any loose attachments or fittings

Fire

Maintenance plans must ensure that the vegetation present on a green roof, wall or facade does not create fire hazards. Dead or dry vegetation must be removed as part of regular maintenance. Fire resistance can be increased by installing breaks in the vegetation or using plants with low biomass (such as native grass tussocks with a low amount of leaf matter). Green facades with deciduous or evergreen climbers are unlikely to create a fire risk as long as dry leaf litter falls away cleanly and is removed during routine maintenance. Vegetation on green walls that receives regular irrigation and maintenance does not pose a fire hazard.

8.3 Plant nutrition

An important element of maintenance is ensuring that plants receive adequate nutrition. This section provides information on nutrition for roofs and facades. Walls are not addressed here because green wall installers will provide specific instructions for meeting the nutrition requirements of the particular plants in the particular wall. Fertilisers for green walls are delivered in liquid form, via the irrigation system (see Chapter 6.3).

In consultation with the designer and client, establish the lowest appropriate application rate for controlled release fertilisers (CRF). The aim is to provide sufficient nutrition for strong plant performance while minimising nutrient loss into irrigation/stormwater run-off. As such, fertiliser rates are usually significantly lower than those recommended for garden or container plants. Where the plantings are limited to succulents there may not be any ongoing addition of fertiliser.

CRF is the most suitable choice for plant nutrition in green roof settings or green facades in containers. The fertiliser comes in the form of water permeable resin granules or beads and is applied on the substrate surface but should be raked or mixed through, ensuring an even distribution. Each rain or irrigation event dissolves a small amount of the inorganic nutrients stored in the bead. If the roof or container is being irrigated from below (a sub-irrigation system) then it is important to mix the fertiliser well into the substrate.

The elevated temperatures on a roof or facade can lead to excessive fertiliser loss and damage plant growth. For Australian natives on green roofs, low phosphorus CRF can be used at half to quarter of the rate recommended for garden or container plants.

Liquid fertilisers are not suitable for routine use on green roofs, as nutrients are more likely to leach out of the mix and leave via stormwater run-off.

Facade greening planted in the ground in a good quality, sandy loam topsoil should not require additional fertiliser. The addition of composted organic matter once or twice a year to garden beds where facade greening is planted will supply nutrients and improve water retention. CRF suitable for the species planted may be incorporated into the garden beds, if desired, according to the rates recommended by the manufacturer.

Visual inspection plays an important part in determining whether plants are experiencing nutrient deficiencies (see *Growing Media for Ornamental Plants and Turf* for further information).

Monitoring of fertiliser levels

It is useful to undertake soil testing of pH and electrical conductivity to establish the conditions under which plants were started. Ongoing, strong plant growth and coverage is the best sign that growing conditions are suitable. As long as there are no problems with the performance of the plants, the manufacturer's recommendations for rate and frequency of fertiliser application may be followed. If plants do not perform well, or there are any signs of nutrient deficiency, a sample of growing substrate should be collected for testing of pH and electrical conductivity (EC) or total dissolved solids (TDS), following the same test procedure as was used at planting. Additional fertiliser should be added if EC or TDS results suggest nutrient levels are simply running low. If possible this should be incorporated through the growing substrate to ensure its even distribution, though this may be difficult to achieve for green facade containers installed at elevation.

This guide has been developed in collaboration with government, industry and universities. It provides advice specific to conditions in Victoria, Australia. It is hoped that this guide will help to increase the number of high quality, multifunctional green roofs, walls and facades to make our cities more liveable and sustainable.

Internal green wall at Mider Investments, South Melbourne, Image: Fytogreen